23 Gully Erosion in I. R. Iran: Characteristics, Processes, Causes, and Land Use

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Abstract

Gully erosion due to land destruction and depletion of soil moisture, especially in drought periods, has an important role for decreasing biomass production in Iran. The aim of this study was to determine the characteristics, processes, and the main causes of gully incision. Satellite images, aerial photos, and anecdotal evidence with field measurements were used to obtain information to answer the research questions. The results of this study indicated that Iranian gullies with an area more than 1,420,000 ha were distributed from coastal zones to highlands with an altitude higher than 3000 m above the sea level. They occurred mostly in the areas with precipitation of 100–300 mm and 500–1000 mm. Gullies are dominant more in semi-arid, arid, and Mediterranean climates. Most of the studied gullies are continuous and valley side. The survey of the view plans of the gullies indicated that surface runoff was the dominant hydrological process for gully incision. The results revealed that the rangelands and forests area decreased while rain-fed farms and barren land increased during the last decades. Most Iranian gullies were located in the altitude of 0–500 and 1000–2000 m above the sea level. Overgrazing and land-use change from rangeland and forests to cultivated lands were the main causes of gully erosion. Data showed that Iranian gullies with an average length and depth equal to 570 m and 2.8 m produced 21 m^3/m sediment per unit gully length.

Keywords

Gully erosion · Land use · Erosion processes · Iran

23.1 Introduction

Soil erosion is recognized as the most important factor for soil degradation and many environmental problems in the world (Kropacek 2019; Fang et al. 2019; Gutierez et al. 2009). Gully erosion is more important than other types of water erosion because of limited research, its unknown aspects, and higher contribution for sediment production and damage (Poesen et al. 2003, 2017; Zhang et al. 2019). Gully erosion causes on-site and off-site problems, damages such less trafficability due to breaking the roads and bridges (Soufi 2005; Soufi 2009; Soufi et al. 2017; Soufi and Bayat 2015, 2016; Rey et al. 2019) and decreased biomass production of croplands and rangelands (Nyssen 2001; Avni 2005). Due to the lack of a detailed data bank for gully erosion in the world (Poesen et al. 2003) and also Iran about gully characteristics, its environment and impact on decreasing the biomass and water depletion, especially during drought periods, this study was conducted throughout Iran.

Gullies are classified based on different factors. They are classified based on the shape of the cross-section and its location in the landscape (Imeson and Kwaad 1980; Brice 1966; Deng et al. 2015), slope of gully banks (Crouch and Blong 1989; Ahmadi 1999), gully length and depth (Campos et al. 2000; Sun et al. 2014), and gully area and depth (FAO 1982). The gully cross-section was divided into V, U, and trapezoid or intermediate (Deng et al. 2015). Deng et al. (2015) emphasized the importance of gully cross-section not only for computing the volume and rate of erosion, but also for understanding the relationship of gullying processes, landforms, land use, and erosional features. Different classifications were used for the gully depth. For example, a small gully is defined with 0.9 m (Ahmadi 1999), 2 m (Refahi

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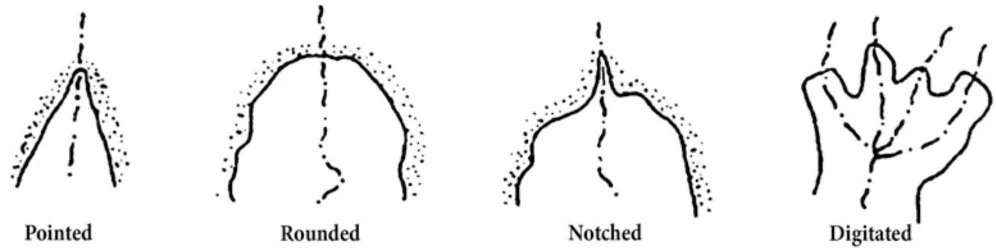

Fig. 23.1 Classification of the view plan of the gully heads (Ireland et al. 1939)

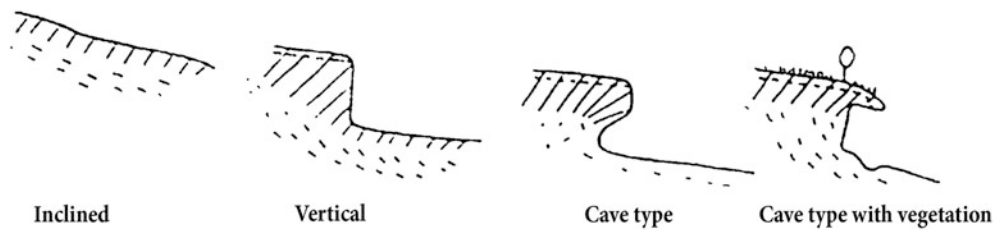

Fig. 23.2 Classification of the longitudinal profile of the gullies (Ireland et al. 1939)

2000), and 1 m by FAO (1982). The medium size gully is defined as 1–5 m depth and the large size was introduced as 5–10 m depth (FAO 1982; Ahmadi 1999; Refahi 2000). Some studies have divided the gullies into continuous (old) and discontinuous (young) in the USA (Leopold and Miller 1965; Heede and Mufich 1974), valley side, and valley floor based on their location (Brice 1966; Imeson and Kwaad 1980). Ireland et al. (1939) classified the view plan of the gullies into six classes including linear, bulbous, dendritic, trellis, parallel, and compound; and the view plan of the gully heads was categorized into four classes including pointed, rounded, notched, and digitated in the USA (Fig. 23.1). They also classified the gully heads based on their longitudinal profile into inclined, vertical, cave type, and cave type with vegetation cover (Fig. 23.2).

Some studies (e.g., Poesen and Govers 1990; Poesen 1989, 1993; Moore et al. 1988) have classified the gullies into ephemeral and permanent based on the possibility of omission, length of life, morphology, location, land use, and dominant hydrologic processes in Europe croplands, Australia and South Africa (Kakembo et al. 2009). The width-to-depth ratio of the gully was used practically by some researchers (Poesen and Govers 1990; Poesen 1993; Deng et al. 2015). Ratios bigger than 1 imply more damages to the cropland and is used for prioritization of its control. Morgan (1995) classified the gullies based on their soil texture and process of gullying. He classified the gullies into three categories including *axial* parallel gullies in coarse soil texture, digitate with vertical head cuts in the loam-clay soil, and frontal with rilled banks and created by tunneling. Some researchers such as Morgan (1995) and Chaplot (2013) introduced categories of gullies based on the mechanism of their formation including those formed by surface runoff, seepage and piping, and mass movement and their combination. Dietrich and Dunne (1993) classified the gully heads into gradual, step (depth < 1 m), and head cut (depth > 1 m). Ahmadi (1999) classified the gullies of Iran based on their length into three categories, small ($L < 120$ m), medium ($L = 120$–240), and large ($L > 240$ m).

Understanding the causes of gully erosion was a big challenge and controversy to develop strategies for gully control during the last century (Graf 1983; Soufi 1997). Causes of gully erosion were of three types (Soufi 1997), (1) deterioration of ecosystem by human impacts (Nachtergaele 2001; Faulkner 1995; Oostwoud Wijdenes et al. 2000; Bork et al. 2001; Soufi 2004; Harvey 1996; Valentin et al. 2005; Castillo and Gomez 2016; Abi et al. 2018; Yu et al. 2019; Okuh and Osumgborogwu 2019; Rong et al. 2019); (2) climate change (Balling and Wells 1990; Castro et al. 2000; Vanmaercke et al. 2016); and (3) intrinsic or random change in the ecosystem (Starr 1989; Soufi 1997). Gully incision and development are attributed to severe grazing by cattle and climate change in southwest USA (Webb and Hereford 2001), after European settlement in the east of Australia since the last 200 years (Prosser and Winchester 1996), change of vegetation cover by humans in England (Harvey 1996), high pressure on land use, and intense rainfall in fourteenth century in Germany (Bork et al. 2001). Pine plantation after clearance of the *Eucalyptus* forest and soil plowing was introduced as the main factor for massive gully erosion in southeast Australia (Soufi 1997). Monsiers et al. (2015) found that cropland with exclusive drainage ditches was most vulnerable to gully development. Increase in the cultivation of corn in central Belgium (Nachtergaele 2001) or increased almond plantation without terracing after destruction of native Mediterranean vegetation cover or increased plantation areas within the catchments of SW Spain (Gutierez et al. 2009) have been proposed as one of

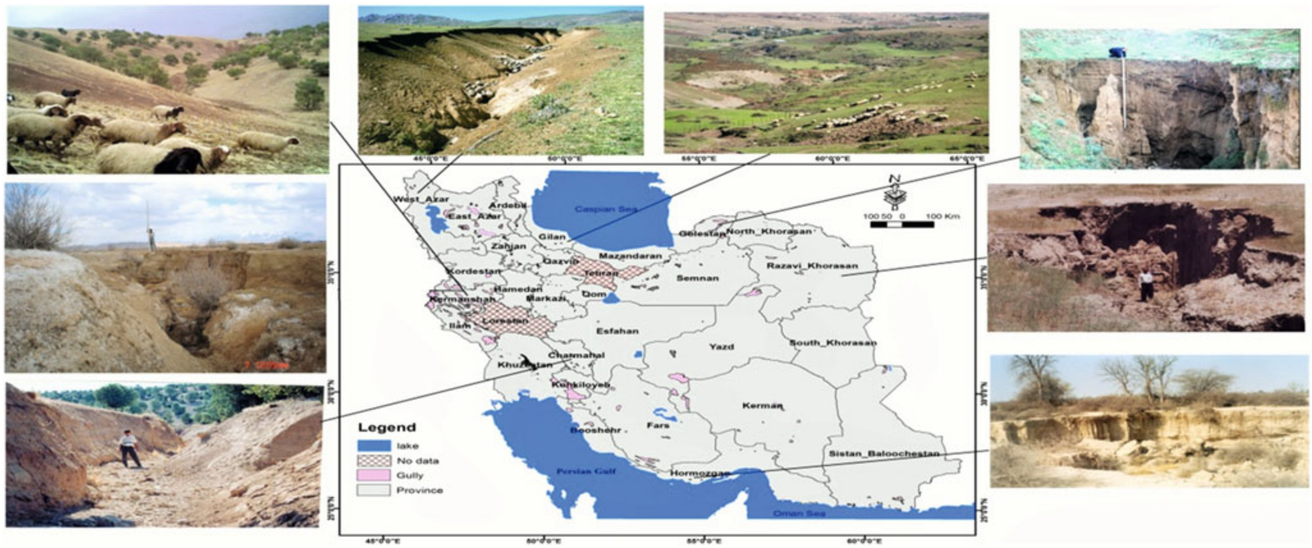

Fig. 23.3 The provinces studied for gully erosion in Iran

the main factors for gully erosion in South Spain (Faulkner 1995; Oostwoud Wijdenes et al. 2000). Svoray (2009) believed that unpaved roads had a greater influence on the location of gully heads than tillage direction in Northern Israel. A recent review by Vanmaercke et al. (2016) indicated that gully head retreat was significantly correlated to the runoff contributing area and rainy day normal. They found that land use and soil type had no significant correlation with gully head retreat in different parts of the world. They believe that gully erosion will become more intense and widespread in the following decades as a result of climate change.

Nowadays, human impacts are introduced as the most important factor for gully incision. In a large scale, land use plays an important role in gully formation. For example, there is less gully erosion in the forests, but it is more in rangelands and croplands. The reason is decline in the range condition due to overgrazing and reduced resistance of the soil surface in croplands. Therefore, changes in the land use from natural to cultivated land have increased the risk of gully incision and development such as southeast highlands of Vietnam (Valentin et al. 2005). In similar land uses, gully erosion depends on topography. That is, lands with steeper gradient might have more gully erosion. Although human impact or climate change had an important role in gully erosion in some parts of the world, coincidence of these two factors has created a complex situation for determining the dominant factor. Therefore, it was stated that the combination of human impacts such as land-use change with intense rainfall is followed by gully formation and/or development (Valentin et al. 2005; Vanmaercke et al. 2016). The type of gully affects the rate of soil erosion (Deng et al. 2015). The rate of gully erosion in ephemeral gullies was 10 times more than the lateral ones in central Belgium (Poesen et al. 1996). The share of gully erosion also depends on the soil texture and rock fragments on the soil surface. Evans (1993) found that the share of gully erosion was more in the heavy soil textures in England. Poesen et al. (1998) stated that gully erosion is dominant on the soils with high rock fragments and in homogeneous soils. Field observation indicated that gully erosion had more share in grasslands (Bradford and Piest 1980) and poor rangelands (Soufi 2004). Data collected from the highlands of Ethiopia (Nyssen 2001) indicated that the contribution of gully erosion increased from 33% to 55% after road construction due to runoff concentration.

23.2 Materials and Methods

23.2.1 Study Area

The study area covered Iran with 15° latitude (25°–40°N) and 20° longitude (44°–64°E) (Fig. 23.3). Mountains such as Alborz and Zagrus and Caspian sea, Persian Gulf, and Oman sea play important roles in local variation in precipitation and temperature throughout the country. Therefore, different climate zones are the result of this variation. The mean of annual precipitation, temperature, and slope are 236 mm, 18.4 °C, and 8.7%, respectively. Based on DeMarton's method, there are six arid climates; semiarid climates are dominant and the other including the Mediterranean, humid, semi-humid, and extra-humid cover a limited area in the country.

23.2.2 Methodology

Regions with gully erosion were determined in four steps. At first, we talked to the provincial experts of natural resources office to collect the name and location of the regions with gully erosion that had an area equal or larger than 500 ha in order to show them on a topographic map with a scale of 1:250,000. The second step consisted of using the satellite images and recent aerial photos obtained in 1984–1987 to review the gully sites mentioned by experts. The third step was field surveying and recording the position of gully boundaries with GPS. In the fourth step, the position of gully erosion in each region was determined on available topographic maps with scales 1:250,000, and map of gully erosion for Iran was prepared using GIS. Permanent gullies were mapped by digitizing orthophoto maps in Arc/info 3.5.2 GIS and converting them to shape files using Arcview 3.2 GIS. Then, the type of the climate for each gullied region was determined, using developed DeMarton's climate map prepared by Jamab office (Ministry of energy). At least two gully regions were selected in each climate zone in each province. In the next step, three representative gullies were selected in each gully region of each climate zone in each province. A questionnaire was filled out with field survey and lab activity for each representative gully. Location of the gully system on the valley side or valley floor and evolutionary period of each gully system, continuous (old) or discontinuous (young), were determined by field observation. The altitude of the gully system from the sea level was recorded using GPS. The shape of the gully view plan was classified based on Ireland et al.'s (1939) classification. Morphometric measurement of the gullies including length, depth, top, and bottom width was carried out using tape meter in the field. Measurement was carried out in each uniform reach and also in the gully head, 25, 50, and 75% of the gully length from the head cut. Soil characteristics were analyzed from the soil samples collected from the gully heads and gully banks from the surface layer where dominant plant roots existed. Particle size and bulk density were determined using a hydrometer and steel cores, respectively. The cores were dried up in an oven for 24 h at 105 °C. Bulk density was calculated by dividing the dry weight by the volume of the cores. Organic carbon was measured using the Walkley-Black method. Ec and pH were measured by Ec and pH meter device, using saturated soil extract. The levels of potassium and sodium were measured, using a flame photometer. Calcium and magnesium levels were measured, using titration with EDTA (Handbook no. 467, Soil and Water Research Institute 2008). The longitudinal profile of the gullies was surveyed using theodolite. Slope gradient of areas draining to gully heads and banks was measured using Sento clinometers. The current and previous land uses were determined by field observation and anecdotal evidence (aerial photos and talking with old residents in the region), respectively. The causes of gully incision and development were determined using anecdotal evidence and field survey. The map of gully erosion for Iran was prepared using GIS. Statistical parameters were calculated using Excel 2007 and SPSS 23.

23.3 Results and Discussion

23.3.1 Area of Gully Erosion

Gully erosion was studied in all provinces of Iran, but the results of two provinces Theran and Lorestan were not presented (Fig. 23.4). Khorasan Province is presented as a unified province in data tables because it was not separated during our study, but the location of gully erosion is indicated throughout northern Razavi and southern Khorasan provinces on the digital map of gully erosion (Fig. 23.4). Totally, 141 regions of gully erosion were surveyed in the presented provinces of Iran. The total area of gully erosion in Iran is more than 1,429,954 ha. Kermanshah and Isfahan with an area equal to 409,895 ha and 256.52 ha had the maximum and minimum areas of gully erosion among the provinces in Iran (Fig. 23.5).

23.3.2 General Characteristics of the Gullies

Results of this study indicated that 59% of the gullies are located on the valley sides (Fig. 23.6a). Eighty-four percent of them are continuous (old) and only 16% of them are young (Fig. 23.6b), which implies most of the sediments from the gullies (old one) are transported to downstream and reservoirs. Therefore, alternatives for gully control should be done for young (discontinuous) gullies. Comparison of geologic formation indicated that 51% of gullies are located on Marls or older formations (Fig. 23.6c), which represent rangelands or rain-fed farms and the remainder is located on the quaternary. Results indicated that gully heads had 40% and 33% pointed and digitated view plans, respectively (Fig. 23.6d). This means 73% of gully incision and/or development is caused by uncontrolled surface runoff. The survey of general view plan of the gullies revealed that 60% of them had dendritic view plan (Fig. 23.6e); this indicates the surface runoff as dominant hydrological process for gully incision. About 38% of the gully view plans belong to linear view plan (Fig. 23.6e); which means this sort of gullies were formed due to flood concentration such as culverts or bridges construction without stabilization alternatives at downslopes or breaking of earth dikes due to floods.

About 38% of the gully heads had vertical long profiles (Fig. 23.6f); this means they have a plunge pool and need emergency measures to mitigate their development. More than 68% of the gully cross-sections had trapezoid and V shape (Fig. 23.6g), showing that there is a resistance layer in

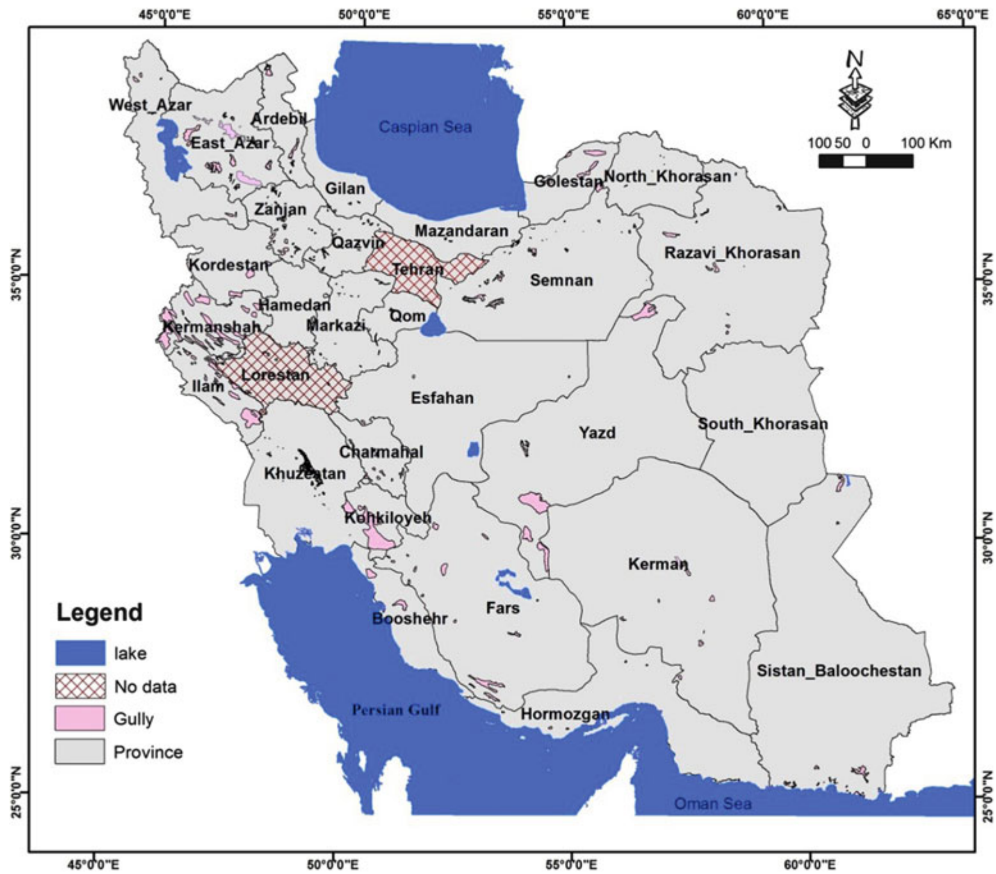

Fig. 23.4 Map of gully erosion in Iran

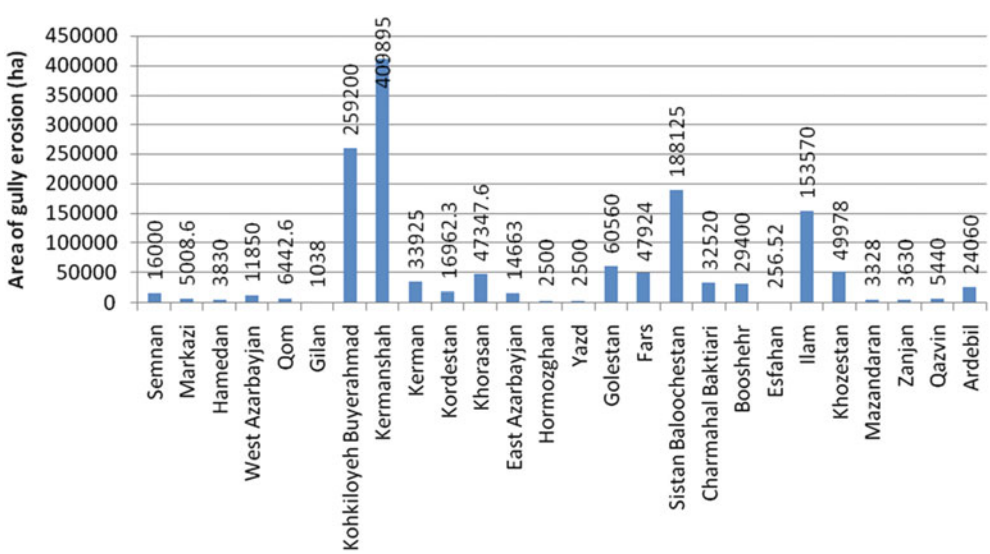

Fig. 23.5 Comparison of the area of gully erosion in different provinces in Iran

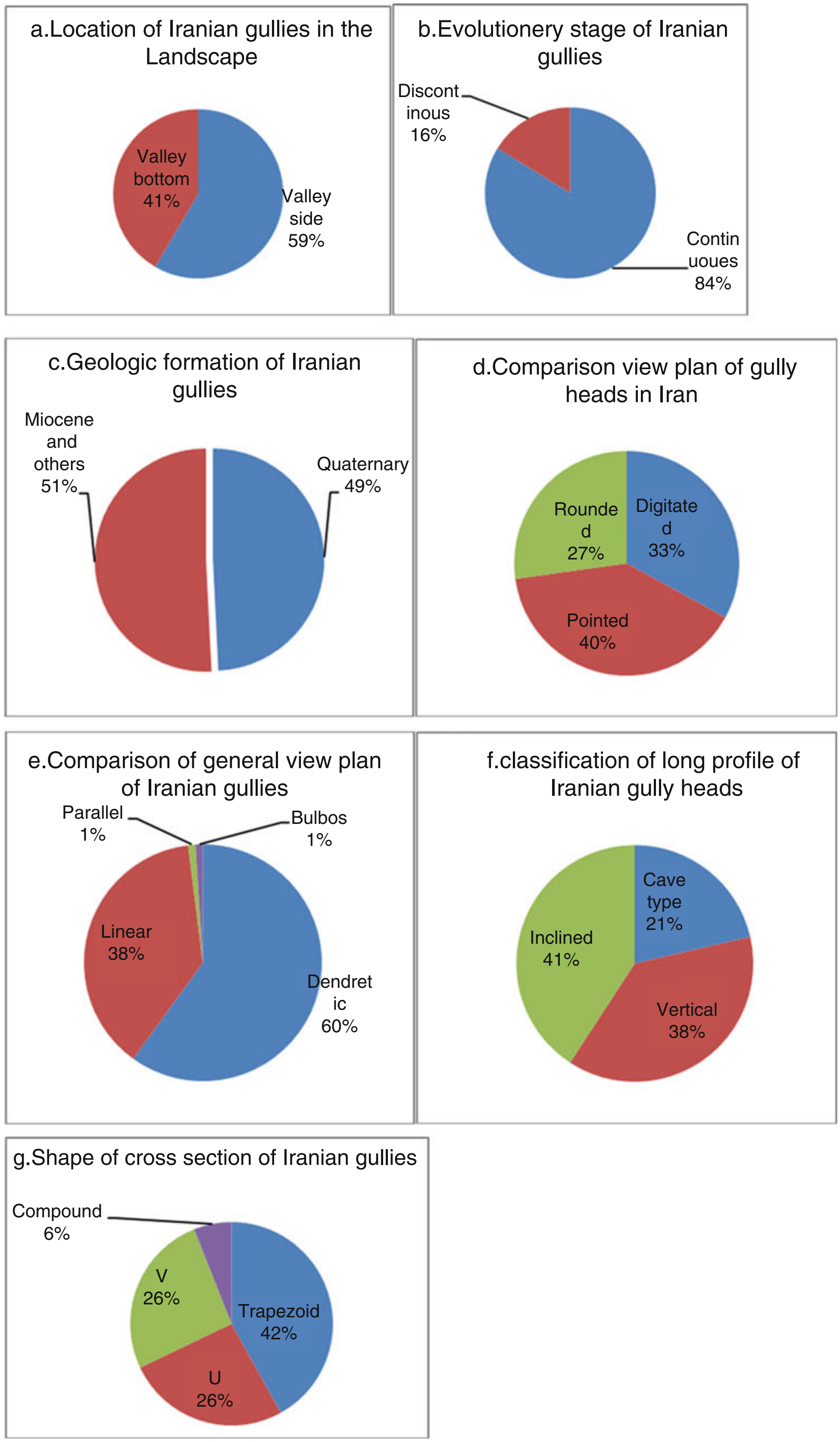

Fig. 23.6 Comparison of Iranian gullies regarding their location in the landscape (**a**), state of evolution (**b**), geologic formation (**c**), gully head view plan (**d**), general view plan of gullies (**e**), long profile of gully heads (**f**), and shape of the cross-sections (**g**)

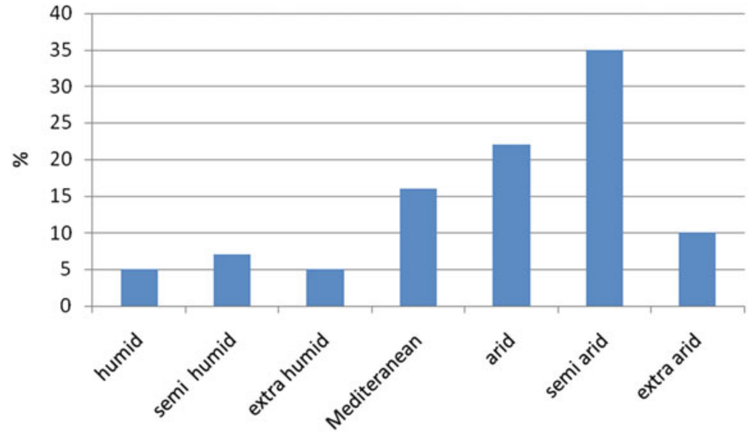

Fig. 23.7 Climate of the regions with gully erosion

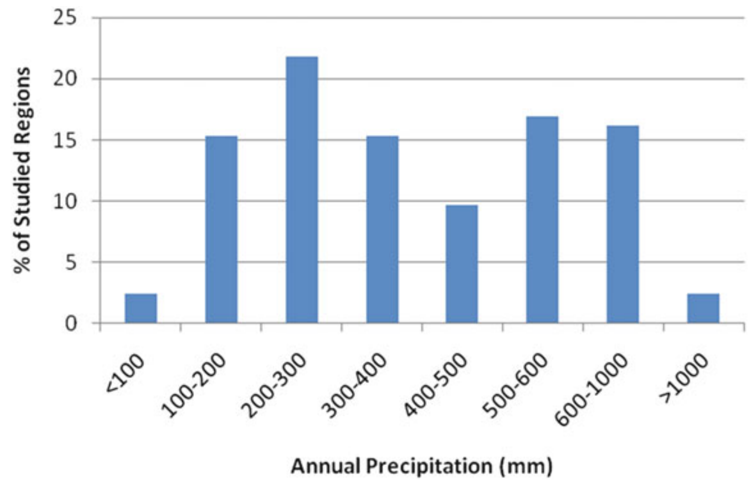

Fig. 23.8 Distribution of Iranian gullies in different classes of annual precipitation

the subsurface, revealing the necessity of an alternative to maintaining the resistance of soil surface to prevent the gully incision, especially in cultivated lands. This result is in the same line with that of Deng et al.'s study (2015). They found that 78% of 456 studied gullies in Yuanmou Dry-Hot Valley, China had intermediate (trapezoid) cross-section. They believed that gully cross-sections were controlled by weathering crusts, soil properties, and vegetation cover.

23.3.3 Climate of Regions with Gully Erosion

Results of this survey indicated that 35% of the Iranian gullies are located in a semi-arid climate. Then, they are distributed in arid and Mediterranean climates with 22% and 16%, respectively (Fig. 23.7). These results with our field observations indicate two facts. The first is related to the land-use change in semi-arid and Mediterranean climates from rangeland to rain-fed farms and gardens and the second belongs to overgrazing of arid rangeland and changes in the range condition to poor and very poor conditions.

23.3.4 Precipitation

Gully erosion occurred in the lands below 100 mm and above 1000 mm annual precipitation. The least portion of gullies (2.5%) belong to the class of precipitation below 100 mm and above 1000 mm both with gully incision occurred mostly in 200–300, 500–600, and 600–1000 mm with 22%, 17%, and 16%, respectively (Fig. 23.8). Class 200–300 mm refers to arid rangelands and class 500–1000 refers to new croplands and gardens due to the land-use change.

23.3.5 Land Use

Results in Fig. 23.9 indicate that the rangelands and forests were reduced and cultivated lands including rain-fed farms and gardens increased. Results revealed that rain-fed farms and gardens increased twofolds. Barren lands increased four times. Rangeland decreased from 54% to 35% and forest decreased from 11% to 1%. Deteriorated rangeland and forest increased by 2.5- and 5-folds, respectively (Fig. 23.9).

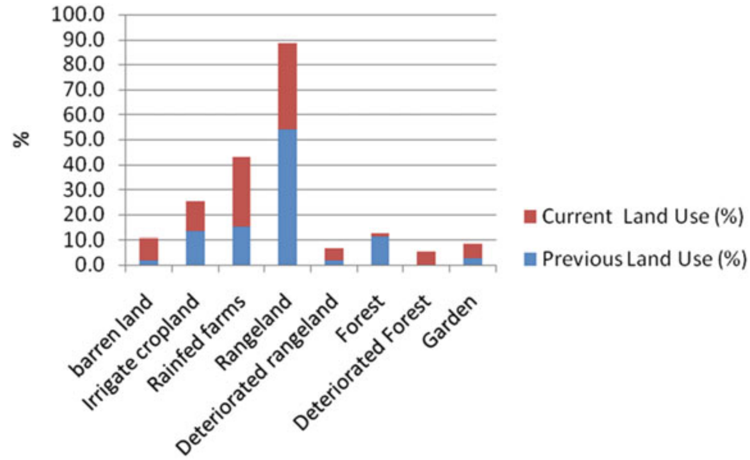

Fig. 23.9 Comparison of land-use change in regions with gully incision

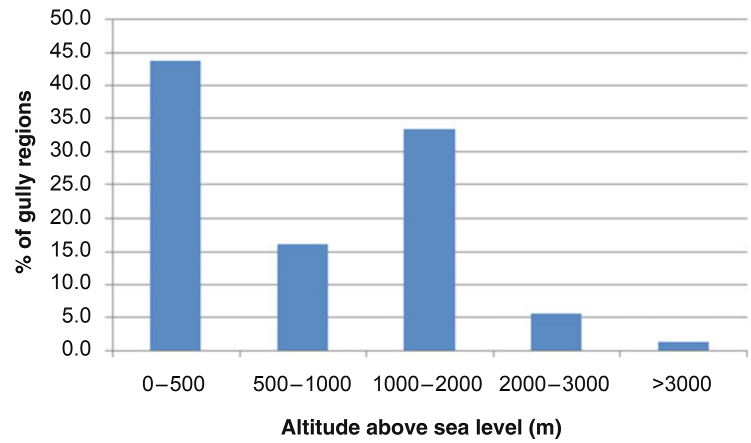

Fig. 23.10 Distribution of Iranian gullies at different altitudes above the sea level

Kakembo et al. (2009) found that 75% of the gullied area occurred on abandoned lands in the Eastern Cape province, South Africa. Gutierez et al. (2009) indicated that gully erosion was closely related to land use, especially with the extent of cultivation areas in the SW Spain. They also stated that there was no clear relationship between the evolution of the gullied area and rainfall amounts.

23.3.6 Altitude Above the Sea Level

Figure 23.10 indicates that gully erosion happened in lands around the Persian Gulf, inland lakes, the Caspian sea and in highlands with over 3000 m altitude. Most of the Iranian gullies were distributed in classes 0–500 m and 1000–2000 m above the sea level with 44% and 33%, respectively (Fig. 23.10). Human interference including overgrazing and increased overland flow due to urban development is the main cause of gully formation in the altitude of 0–500 m above the sea level. The main causes of gully formation in the altitude of 1000–2000 m above the sea level were overgrazing and change in the land use from rangeland and forest to cultivated lands. Kakembo et al. (2009) stated that gully erosion was dominant in concave bottomlands of the Eastern Cape province, South Africa. Mararakanye and Sumner (2017) found that gully formation was associated with duplex soils on colluviums and alluvial deposits on a lower slope where overland flow converges and accumulates in South Africa.

23.3.7 Soil Properties

Soil texture of Iranian gullies is displayed in Fig. 23.11. Seven hundred thirty-two soil samples were collected from the heads and banks of Iranian gullies. Results indicated that loam, sandy loam, clay loam, and silt loam were the most common soil texture with 28%, 24%, 13%, and 10%, respectively (Fig. 23.11). Loam belongs to the gullies of southwest and southeast provinces, sandy loam to coastal gullies, clay loam to the northwest and northern gullies, and silt loam to northeast gullies.

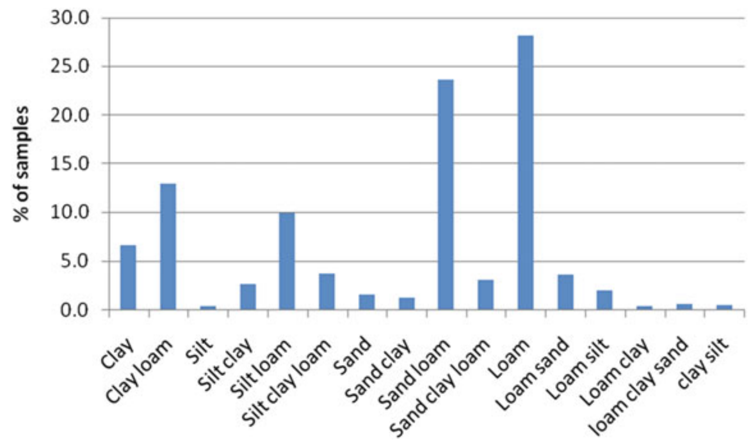

Fig. 23.11 The soil textures of the samples collected from Iranian gullies

23.3.8 Morphometric Characteristics of the Gullies

Table 23.1 compares the dimensional factors and soil loss from gullies in different provinces of Iran. Results indicated that the average length of gullies was equal to 517.4 m. Maximum and minimum gully lengths belonged to Mazandaran with 2900 m and Booshehr with 52.1 m, respectively (Table 23.1). These results show that the classification of Iranian gully length by Ahmadi (1999) could be changed. Ahmadi (1999) classified gullies with a length of 120 m and 240 m as medium, while in this survey the gullies with a length around 500 m are in the medium class. The average top and bottom widths were 7.2 m and 3.0 m, respectively. The maximum top and bottom widths belonged to Yazd and Sistan and Baloochestan provinces with 15.3 m and 11.7 m, respectively (Table 23.1). The minimum top and bottom widths of the gullies with 2.0 m and 0.7 m, respectively, belonged to Semnan province (Table 23.1). The average depth of the gullies was equal to 2.8 m, which belongs to the medium size gully. The standard deviation for the gully depth presents the medium size gullies with a class of 1.2–4.2 m for this study. Maximum and minimum depth of the gullies belonged to Yazd and Semnan with 8.0 and 0.8 m, respectively (Table 23.1). Results indicated that the average soil erosion by gully was 21.2 m^3/m of gully length (Table 23.1). The maximum and minimum of soil erosion by gullies belonged to Yazd and Semnan with 151.9 m^3/m and 1.4 m^3/m, respectively. Comparison of data showed that gully erosion in some provinces such as Mazandaran, Sistan and Baloochestan, Kohkiloye and Boyerah, Kordestan, Esfahan, Khorasan, Golestan, Yazd, and Hormozghan was higher than the average rate (21.2 m^3/m) of erosion (Table 23.1).

23.3.9 Causes of Gully Erosion

Figure 23.12 shows the causes of gully erosion in Iran. Results indicated that 65% of data belonged to human impacts and 35% to natural factors such as rainfall intensity and soil erodibility. Among different aspects of human impacts, overgrazing with 32% and changes of rangeland and forest with 17% had a high contribution to the causes of gully erosion in different parts of Iran (Fig. 23.12).

23.4 Conclusion

This study indicated that gully erosion distributed throughout different parts of Iran with an area more than 1,420,000 ha from the coastal zones to highlands with an altitude higher than 3000 m above the sea level. Although gullies are observed in different climate zones, most of them are located in semi-arid and arid zones. Eighty-four percent of the gullies are continuous (old). This indicates that most of the sediments from the gullies were transported downslope. Therefore, the priority for gully control belongs to saving lands, infrastructures, and residential areas. The dominant general gully (60% dendritic) and heads (73% digitated and pointed) view plans show the action of the surface runoff as the dominant hydrological process for gully incision and/or development. Forty-one percent of Iranian gullies had loam and clay-loam soil texture. The results of gully view plan and soil texture are in the same line with Morgan's (1995) and Deng et al. (2015) conclusions. The results indicate that gully incision coincides with changing rangeland and forest to cultivated land including croplands and gardens. Overgrazing and changing the rangeland and forest were the dominant causes of gully erosion in Iran.

Table 23.1 Comparison of the average length, top width, bottom width, volume and volume per unit length of Iranian gullies in different provinces

Provinces	Ave. length (m)	Ave. top width (m)	Ave. bottom width (m)	Ave. depth (m)	Ave. volume (m^3)	Ave. vol./unit length (m^3/m)
Yazd	650.0	15.3	5.5	8.4	98,707.8	151.9
Hormozghan	116.0	9.3	8.4	1.9	3281.4	28.3
Golestan	274.8	9.8	3.6	3.2	7995.3	29.1
Kerman	135.1	5.2	1.7	1.4	1059.9	7.8
Qom	140.3	10.5	1.0	2.4	1970.0	14.0
Fars	127.1	7.3	2.0	2.6	2510.5	19.8
Semnan	79.3	2.0	0.7	0.8	109.1	1.4
Khorasan	217.7	4.5	2.7	3.0	4426.3	20.3
Zanjan	564.3	5.3	1.5	1.7	3853.9	6.8
Charmahal and Baktiari	762.5	6.1	1.9	2.6	9970.5	13.1
Booshehr	52.1	5.2	2.0	1.8	772.8	14.8
Esfahan	244.1	11.2	1.2	2.4	6966.4	28.5
Kermanshah	678.2	7.2	1.4	2.3	6592.1	9.7
Kordestan	2183.3	8.0	4.0	3.7	48,469.3	22.2
Gilan	293.5	4.2	2.6	1.2	1147.6	3.9
Markazi	83.8	6.7	1.6	3.2	1101.3	13.1
Kohkiloyeh and Buyerahmad	300.0	10.3	5.1	4.4	10,190.4	34.0
West Azarbayjan	214.0	6.4	1.4	2.1	1727.1	8.1
East Azarbayjan	265.2	4.6	2.2	2.6	2294.7	8.7
Hamedan	439.0	4.1	1.4	1.5	1809.5	4.1
Sistan and Baloochestan	1690.0	14.3	11.7	3.2	69,258.7	41.0
Qazvin	162.8	3.0	1.3	1.6	532.0	3.3
Ardebil	113.9	7.0	3.1	2.9	1664.5	14.6
Ilam	392.9	10.1	1.7	2.7	6219.9	15.8
Khuzestan	183.3	6.5	3.0	2.4	2085.4	11.4
Mazandaran	2900.0	6.9	3.5	7.2	108,576.0	37.4
Zanjan	707.0	4.3	4.3	2.4	7330.2	10.4
Average	517.4	7.2	3.0	2.8	15,208.2	21.2
Max.	2900.0	15.3	11.7	8.4	108,576.0	151.9
Min.	52.1	2.0	0.7	0.8	109.1	1.4
SD	681.2	3.2	2.4	1.6	29,718.8	28.2

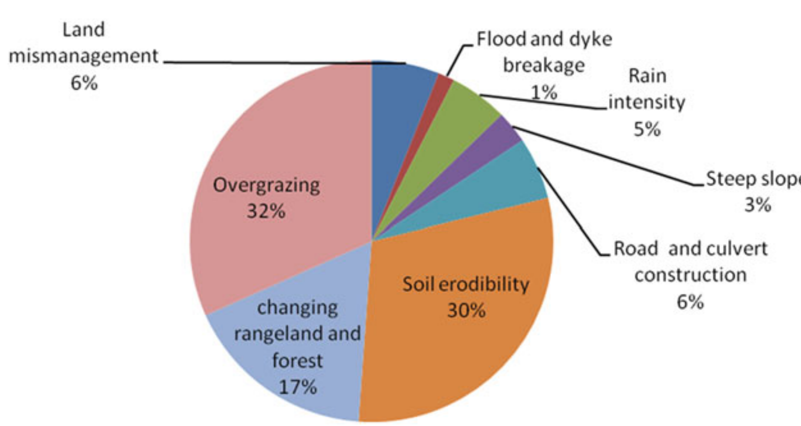

Fig. 23.12 Comparison of the causes of gully erosion in Iran

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