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Water Harvesting and Urban Centers in Dryland Alluvial Megafans: Environmental Issues and Examples from Central Iran

N. Arzani

***Abstract*—Underground and surface water harvesting systems in alluvial fans were among the very important environmental control on urban growths in drylands. Traditional underground water supply systems, known as Qanats (kareeze), were used for centuries as a very efficient method for water harvesting in arid lands of central Iran. Surface flood-water harvesting methods have also been recently applied for aquifer recharge in such environmental setting. However, climatic changes, increasing population and industrialization, during the last five decades, made that the water resources quite inadequate and a competition happened to pump out water from the shallow to deep aquifers of the alluvial-fan systems. This resulted in serious environmental problems, depending on the geographic positions of the urban areas on the fan surface. Desertification, wind erosion/deposition, water and soil salinity crisis and immigrations affected and especially concentrated in the cities and villages located in the down-fan areas. This paper, based on lessens learned from some of the implemented cases in Iran, examines the water harvesting projects in different types of alluvial megafans under arid to semi-arid environmental conditions. It is very important to consider the type of alluvial fans to apply any method for water harvesting projects.**

***Index Terms*—Alluvial megafans, dryland, flood-water harvesting, Qanats**

I. Introduction

Water undoubtedly is a major environmental constraint in drylands and traditional underground water supply systems and or surface-water harvesting methods were used in such environmental setting. Flood-water harvesting is defined as a method for inducing, collecting, storing and conserving local surface runoff for agriculture in arid and semi-arid regions [1], [2]. Drylands cover about one third of the Earth's land areas, where desertification and drought is a main threat to the environment and its ecosystem [3]-[5]. Deserts cover a considerable area in central Iran and are fault-bounded depressions with harsh environmental conditions (Fig. 1).

Drylands precipitation is mainly as short-term rainfall depth often episodic. As a result, dryland fluvial systems are primarily ephemeral and often dry for extended periods. Erosion and depositional in these systems are, thus, largely event-based phenomena. Infiltration rates are normally highest in the coarse sediments of the mountain front and hillsides and the lowest are in the impermeable soils of the flood-plain areas of the alluvial fan systems.

There has been always an attempt to control at least part of this natural environmental system and obtain the minimal conditions, most importantly water resources and soil, for an urban growth. Traditional underground water supply systems, known as Qanats (kareeze), were used in drylands and desert margins of central Iran as dependable, renewable supplies of water to the old villages, towns and cities for centuries [e.g. 6]. This water harvesting method was generally based on the gravitational water flow through underground trenches (up to tens of kilometers long) in alluvial fans and from upstream hillsides to downstream farm areas. Each Qanat system is composed of a mother well, which is the deepest and the first well dug in the starting point and in the most upstream (usually in the hill sides) parts of this system, and it is the beginning of the underground tunnel beneath of this well. The location of mother well and its depth depend on its geographic position on the fan and the underground water tables. It should be enough deep to collect the water and drain it into the underground tunnel and finally into the farm lands (see [6], [8] and [18] for details).

In dryland climates, low frequency/high magnitude flood events are very important natural hazardous events. However, episodic very large floods can be controlled and changed into useful water resources. Storm floods in gullies and ephemeral rivers diverted onto cropped land, play an important role in several arid to dry semi-arid lands. Surface-water harvesting techniques is believed to have originated in Iraq over 5000 years ago, in the so-called Fertile Crescent, which is believed to be the very cradle of agriculture. In both India and China, the technique was in use more than 4000 years ago [7]. There are two major forms: in *situ rainwater harvesting*, collecting the rainfall on the surface where it falls, and *external water harvesting*, collecting runoff originating from rainfall over a surface elsewhere.

In order to enable supply of harvested surface runoff flow according to human needs over time, storage is inevitable, which can be done in various types of surface and sub-surface storage systems. The hydrological processes relevant to water harvesting practices are those involved in the production, flow and storage of runoff from rainfall within a particular project area. The rain falling on a particular catchment area can be effective (*as direct runoff*) or ineffective (*as evaporation, deep percolation*). The quantity of rainfall which produces runoff is a good indicator

Geology Department, University of Payame Noor, Esfahan, Iran(Email:arzan2@yahoo.com).

of the suitability of the area for water harvesting. The land form, slope gradient and the relief intensity are among the important parameters to determine the type of water harvesting system. Alluvial fan systems are one of the ideal geomorphological locations for such projects. The terrain analysis can be used for determination of the length of slope, a parameter regarded of very high importance for the suitability of an area for macro-catchment water harvesting. With a given inclination, the runoff volume increases with the length of slope. The slope length can be used to determine the suitability for macroor micro- or mixed water harvesting systems decision making. However, dry area ecosystems are generally fragile and have a limited capacity to adjust to change. If the use of natural water resources is suddenly changed the environmental consequences are often far greater than foreseen. Consideration should be given to the possible effect on other water users, both in terms of water quality and quantity. New water harvesting systems may intercept runoff at the upstream part of the catchment, thus depriving potential down stream users of their share of the resources.

The water shortages in the populated villages, towns and cities of central Iran, during the last 50 years, have become increasingly acute and modern pumping technologies, with access to deep groundwater reservoirs, gradually has been replaced the traditional water harvesting systems of Qanats [e.g. 8]. This competition particularly stressed the down-fan areas and imbalanced the natural and social media with major environmental issues. Desertification, wind erosion/deposition, water and soil salinity crisis and immigrations affected and especially concentrated on the cities and villages located in desert borders in down-fan areas. This study highlights the importance of water resources and its environmental issues in dryland alluvial fans.

II. General Setting and Methodology

The study area is located along the Gavkhoni-Abarkoh-Sirjan Basin of central Iran, a geographic depression, which is up to 100 km wide and more than 600 km long, running from the northwest to southeast of Iran (Fig. 1B and C). Alluvial fans source from the side valleys and extend towards the centre of this basin, where it is desert and playa. The salty soils of the playa-fringe areas gradually merge intro the true desert with sand dunes and salt flats. The latter was covered with a hallow water, as a lake, part of the year.

The climate of central Iran has changed considerably from the Pliocene to the present. The present climate has become increasingly dry with time and has significantly influenced the flood events on the alluvial fans [9], [10]. The present climate of the area is arid to semi-arid and the average rainfall between 30 and 200 mm in the basin, and up to 300 mm in the headwaters of many ephemeral rivers. The rainfall is usually in the form of heavy showers and thunderstorms resulting in episodic floods. The summer maximum daily temperature (for >15 days) is up to 45 ºC.

The water resources and underground/surface water harvesting in two major types of alluvial megafans in central Iran and in selected cities along the Gavkhoni-Abarkoh-Sirjan depression were studied (Figs. 1 and 2). The general trend (50 years) of these alluvial-fan water resources, urban growth and their environmental issues were assessed.

III. Underground and Surface Water Harvesting in Alluvial Megafans

Underground and surface water harvesting systems in alluvial megafans were the core basis and the very important environmental control on urban growths in drylands. Flood-water harvesting and its hazard management on desert piedmonts and their alluvial fans are particularly challenging. Desert piedmonts host a variety of complex ephemeral flow networks that convey high velocity flows through steep, alluvial channels and across steep, hydraulically and morphologically complex alluvial fan systems. Piedmont is the descriptive term for a relatively broad, generally low relief area at the base of the mountain front that slopes toward the center of the basin. Piedmonts are composed mostly of alluvial sediment (gravel-sand and mud) shed from adjacent highlands by streamflows or debris flows, but they often include complex mixtures of eroded bedrock and various types of surficial geologic deposits and landforms. Alluvial fans are the most common geological and geomorphological features on desert piedmonts and are usually the focus of piedmont flood-water harvesting and flood hazard management. Alluvial fans often resemble extended fans, or conic segments when viewed on maps or aerial photographs. However, the gross planimetric geometry of fans can range from relatively ideal, or classic, fan shapes to more irregular forms bounded laterally by adjacent fans, bedrock outcrops, and relict fan surfaces, among other possibilities.

Alluvial fans are the major hydrological resources in arid lands [12]-[14]. They develop in different sizes and represent small mountain front (Death Valley type) fans to very large fans (megafans), such as megafans in central Iran (Fig. 2). The alluvial megafans have been defined as large mountain-front geomorphic features as fans with an apex to toe length of >30 km and a very gentle slope (0.2° to 1°, see reviews in [14]). The surface areas of such fans are 300 to more than 1000 square kilometers and they usually toe out into the deserts and or playa lakes in drylands [15], [16].

The megafans can be grouped into two types based on the length of their intersection points (fan apex toward the downfan areas) and the site location of the surface flood-water harvesting projects. Type "A" megafans have a short (<5 km) intersection point and the proximal areas of the fans are ideal location for the flood-water harvesting areas (Fig. 2). Type "B" megafans have a long (up to 20 km) intersection point and the distal areas of the fan are usually used for surface flood harvesting projects (Fig. 2). The sediment discharges to water ratios seems to be a key factor in controlling the morphology of the megafans and substantial fan-surface incision and the long length of the intersection points seems to be related to the geomorphological evolution of the fans. The inherent morphology of an alluvial fan results in a predictable distribution of recharge, lateral flow, and discharge zones in the shallow, unconfined to moderately confined fan aquifer sands. This has been complicated with the displacement (faulting) of the rock facies, corresponding to the different parts of the alluvial fan or the underlying bedrocks. Structural geology of the area is also very important, as for example if permeable channel-filled sediments, such as gravels and sands which have the highest recharge, are displaced and enclosed with the impermeable calcareous marls of the flood plain sediments, they could brings about many perched and/or locally confined flow aquifers.

Alluvial megafans were ideal location for the traditional underground water harvesting systems and this has been well recognized by the Iranian, who designed and constructed the sophisticated ancient Qanats, built into alluvial fans as potential hydrofacies in typical sedimentary and geomorphic systems. The underground tunnel length of these Qanats depends on the position of farms and cities on the fan surface (proximal to distal fan areas) and generally can be grouped into short-lengths (<10 km) and long-length Qanats [17], [18]. The latter are up tens of kilometres in length and with a deep mother well, an underground tunnel and a series of vertical shafts, which collects the water and flows through its underground tunnels to the surface of the farms and cities located in the medial and distal areas of the large fans. The length of the underground tunnel normally depends on the slope of the fan surface and the length of the Qanat [18], [19].

The Abarkoh, Ardestan and Nain are three towns, with about 10,000 populations each, developed on large alluvial fans which are as three typical examples of megafans in drylands of central Iran (Fig. 2). These are very old urban areas and were developed in the proximal, medial and distal parts of these large alluvial fans since probably more than 2500 years ago. Few smaller towns and many villages are scattered from proximal, upstream to distal, downstream areas of these alluvial fans. The total populated areas (towns and villages) around each of these alluvial fans, which depend their life's to the alluvial fan water resources, is up to 50, 0000 people. The old traditional agricultural systems were used and still are partly in use in these towns and villages. Qanats were the almost only traditional water supply systems in these cities, towns and villages until 50 years ago. However, in the Abarkoh city, they partly dried out because of using modern technology as deep tube wells. More than 850 shallow (up to 100m deep) to deep (>300 m deep) well competed with 130 Qanats during this period in this city, where less than 15 Qanats are hardly active water supply today [6], [18]. This is different in Ardestan, where limited new technology was used and about 90% of Qanats are still active as the sustainable water supply system.

It is very important to consider the type and sedimentology as well as the geomorphology of alluvial fans for applying any method commonly used in hillslope or small-watershed scale research, on rainfall partitioning on a system scale - studying run-on surface flow from catchment areas, the water balance of water harvesting structures, and the rainfall partitioning in the production systems linked to the water harvesting system. Such research will give important knowledge on how far water harvesting can go in improving crop production, and will form the basis for analysis of spatial up-scaling of water harvesting.

Water resources in alluvial megafans: environmental issues

Alluvial fans were the potential water resources for a long term urban growth in drylands of central Iran. Two types of urban centers, according to the size and type of the alluvial fans, were developed in the studied area: (I) villages and farms developed on small, mountain-front fans with limited water reservoirs and short-length Qanats, (II) cities, villages and farms developed in proximal to distal parts of megafans with long-length Qanats and deep tube wells (Fig. 2). Mountain-front small alluvial fans are not the subject of this study.

Environmental issues are more pronounced in alluvial megafans as recent drought, over population and consumption of water in proximal areas resulted in a drop in water tables in down-fan and medial to distal areas and dried their long-length Qanats. Desertification, dust storm, water and soil salinity crisis and immigrations affected and especially concentrated on the cities and villages located in desert borders and in down-fan areas (Fig. 2 B and C). This is more pronounced where the fall and a major drop in the underground, fresh-water table has raised and invaded the adjacent salty-water tables of the playa lake and this invasion has markedly affected the soil salinity crisis and added to the environmental problems in the down-fan areas [8], [19] and [20].

Despite, recent inter and intra-basin water transfers, new harvesting/irrigation and cultivation methods in the studied area, there has a little progress because of strong cultural and socio-economic aspects. These are real challenges and the future conflicts for the habitants of drylands today and actually it takes time to overcome and control the crisis. What is of the prime importance is to educate, financially support the farmers and involve them in any decision to be made in order to control the environmental issues. It is very critical to rewrite the laws and according to real facts and reconsider them according to the new environmental issues and problems.

IV. Conclusions

Alluvial megafans are one of the important water resources in drylands, but environmentally very sensitive natural areas. Two types of alluvial megafans based on their length of the intersection points (fan apex toward the downfan areas) were recognized, each with a specific site location for the surface flood-water harvesting projects. Type “A” megafans have a short (<5 km) intersection point and the proximal areas of the fans are ideal location for the flood-water harvesting areas (Fig. 2). Type “B” megafans have a long (up to 20 km) intersection point and the distal areas of the fan are usually used for surface flood harvesting projects. Environmental issues is much pronounced in down fan and distal areas of the alluvial megafan systems, where there is a critical balance between surface floodplains and desert conditions and underground alluvial-fan fresh and playa-lake salty waters. Any misunderstanding of this natural condition may bring along serious environmental problems as is discussed above. Although large fans are suitable areas for urban developments in drylands, water resources and local environmental conditions in these sensitive natural systems should be considered carefully.

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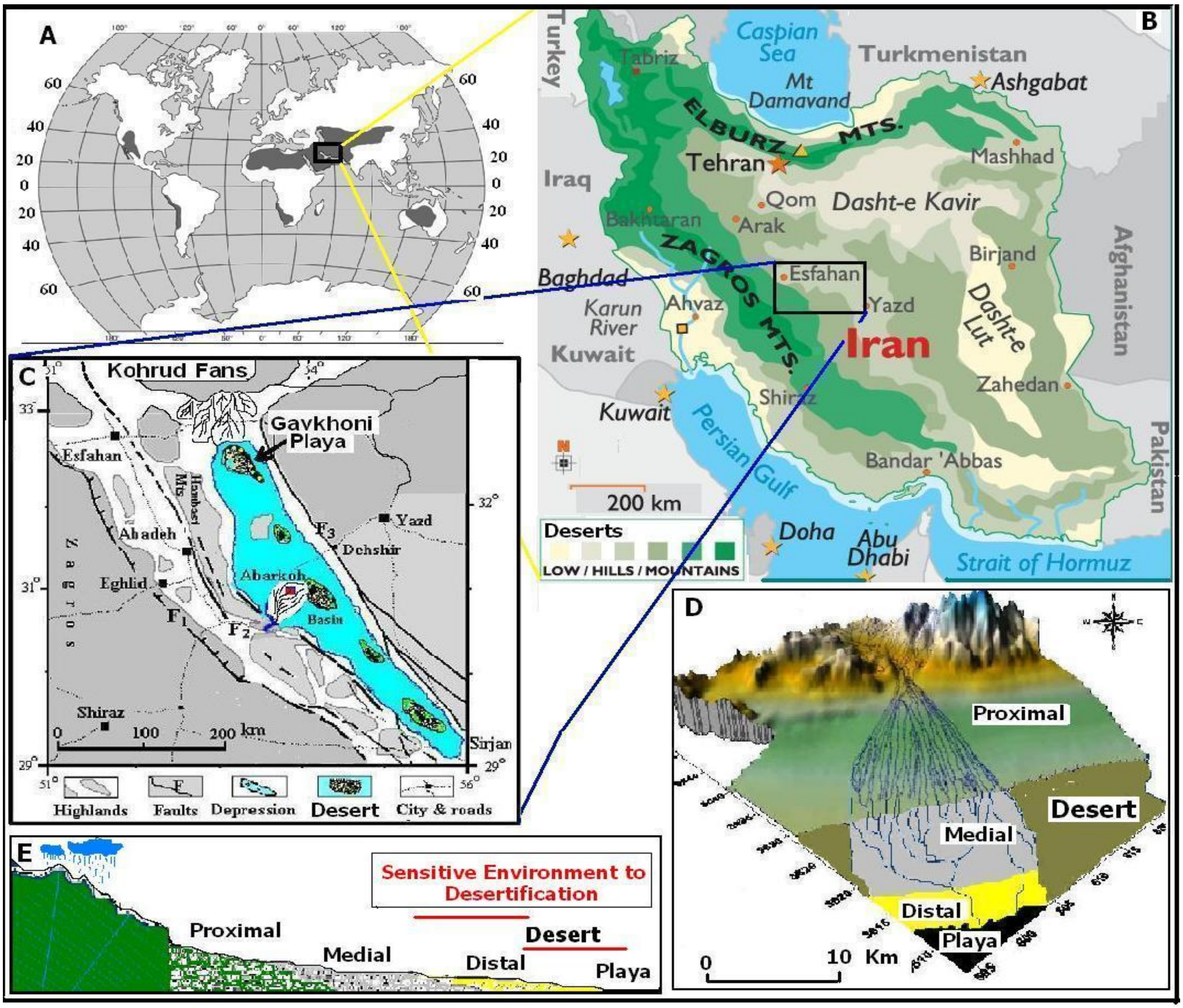

Figure 1. Distribution of the deserts areas in the word (A) Iran (B) and central Iran (C) with the general geomorphology and profile of the alluvial megafan systems (D & E). Alluvial megafans are one of the important water resources in drylands, but environmentally very sensitive natural areas. This is much pronounced in down fan and distal areas, where the alluvial fan system is a critical balance between surface floodplains and desert conditions and underground alluvial-fan fresh and playa-lake salty waters. The medial to distal parts of the alluvial fans, whrer they laterally grade into the playa fringe, are more prone to desertification in drylands.

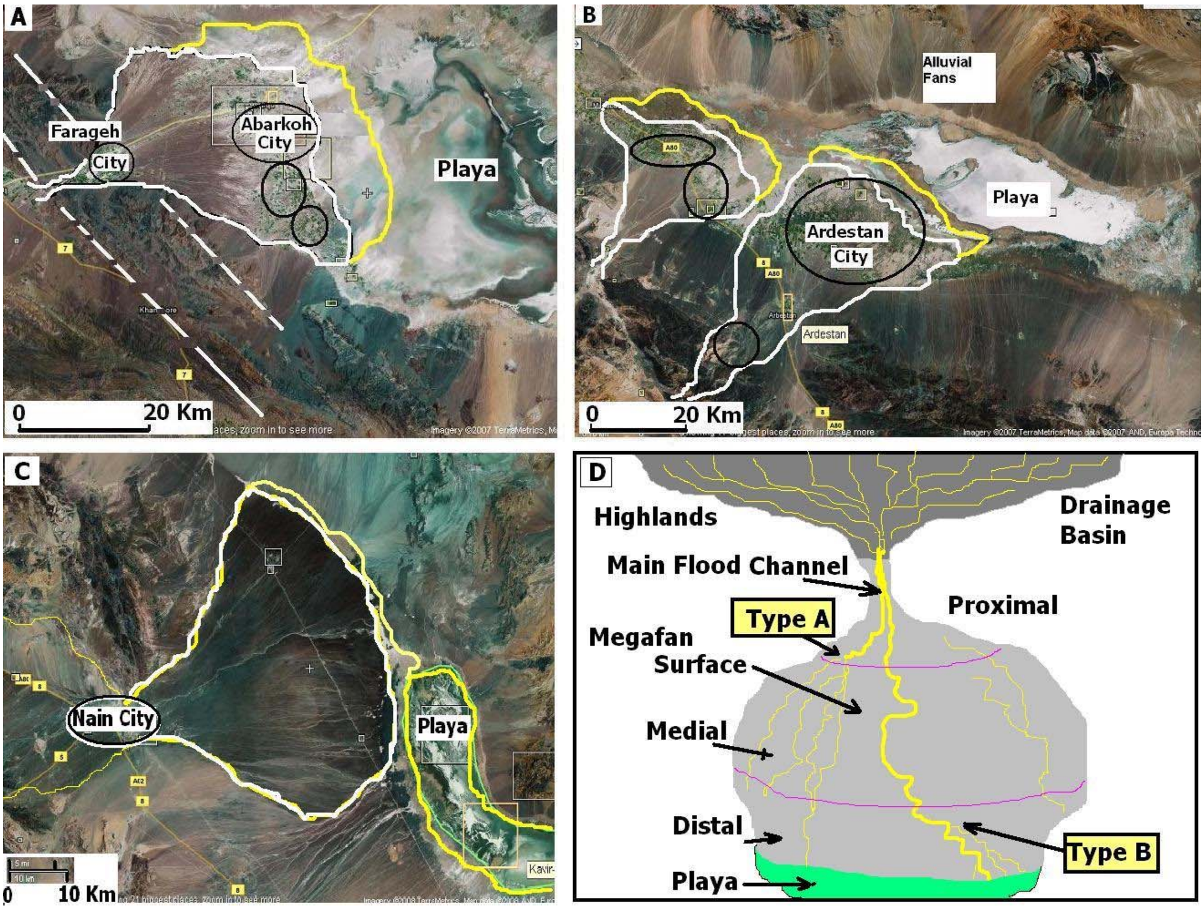

Figure 2. Water harvesting and the location of urban areas in alluvial megafan systems in central Iran. The location of urban areas as circled: location of villages according to the size of the fan in Abarkoh (A), Ardestan (B) and Nain (C) in central Iran. Type A megafans (D), with a short (<5 km) length and are suitable for surface water and flood-harvesting projects and aquifer recharges in their proximal areas, whereas type B, with a long (up to 20 km) intersection point mostly are draining directly to the playa in the distal fan region. The medial parts of the alluvial fans were the best place for underground water harvesting to conduct the water to the surface through the Qanat system and accordingly were the ideal place to develop the citied in dryland of central Iran (see Fig. 1 for location and the text for details). The structural geology of the area and the size of the alluvial fan catchment that collect the precipitations (rainfalls and sediments) determines the size of the alluvial fans and measures their water resources (see [8] and [14] for details).