Evaluation of Qanat Collapse Hazard in Mashhad City (Case study: the zone 11 of municipality of Mashhad, Iran)

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Abstract

Mashhad city has been developed in recent decades. The development of the city towards the routes used to be qanat well is one of the problems that Mashhad city is confronted. Today many of the qanats are under urban areas. These qanats become dry little by little because of successive droughts, developing of the city and drilling deep wells In order to supply water. Contemporary of developing the city, the qanats are filled with earth fill soils uncontrollably and this problem causes ground settlement, cracks and fissures in the ground and consequently damages of buildings and also cracking in the system of water supply. This problem is doubled in west areas of the city because of high buildings and high abundance of qanats in those areas. This paper deals with the main factors that cause qanat collapse. First of all the exact location of the qanats in the zone11 of municipality of Mashhad was studied. Then the main factors that influence the stability and performance of qanats were determined. These factors include: depth of qanat gallery, loading due to surface structures, land use, underground water table and geotechnical properties of the soil. Finally areas with the most potential of collapse hazard are introduced. The results can be used in planning for increasing the security level of buildings and structures in hazardous areas of the city.

Keywords: *qanat; Settlement; zone 11 of municipality of Mashhad; land use.*

Introduction

Mashhad, the second big city in Iran, is the capital city of Khorasan Razavi province. It is located in north east of Iran. The area of the city is about 270 km^2. The population of the city is about 2.5 million people. Every year 13 million people visit this city. More than 25000 qanat shafts were identified by evaluating aerial photos in Mashhad region that most of them are located in west areas of the city. Of course, nowadays most of them dried. In the recent years qanats were covered by buildings and streets due to development of the city toward the west.

Geology

Mashhad plain is divided into three zones. Kopet Dagh sedimentary zone, Ophiolite zone and Binalood metamorphic zone are from north to south respectively. It is located between Binalood and Hezar Masjed mountain ranges. From the hydrological viewpoint, the city is a part of Kashafrood River's basin and it lies on young alluvial deposits of Mashhad plain. The study area includes the eleventh zone of municipality of Mashhad in western part of the city.

The soil type in that part is mainly consisted of gravel and sand that are originated from the southwestern metamorphic mountain. Surface soil type map of zone 11 is shown in figure 1.

Mashhad qanats in general

Mashhad has arid and semi-arid climate so the water resource are limited. The maximum average annual precipitation in 24 hours is 33 mm [1]. Underground irrigation systems called Qanats were used in the past few decades in Iran due to scarcity of water [2]. Qanats which are the traditional water piping systems are consist of an underground tunnel connected to the surface by a series of shafts. The tunnel has a gentle slope. This system causes water that comes in to view on the surface by gravity force. The qanat system was used where there is no surface water and was originally invented by Iranians [3]. In last decades, high demand for fresh water and the technology of drilling of deep wells have been resulted in death of Kariz (qanat) civilization [4]. There are two groups of qanats in urban region; some of these qanats are active i.e. they have water. The next group consists of old qanats related to the past decades or even past centuries that are inactive. These old qanats are now dry and partially collapsed. In regions with collapsed qanats, construction is not safe and soil test is necessary [5].

In Mashhad region there are more than 100 qanat chains and 26278 qanat shafts that identified by using aerial photos with 1/20000 scale [6]. Bahr Abad qanat with 22 km length and 133 m depth of mother well is the longest and deepest qanat in Mashhad area.

Figure 2 shows the qanat chains in the urban area of Mashhad. Most of their mother wells are located in the western and southwestern parts out of the city. Also, appearances (The place where water comes into view on the surface) are located in central part of the city [7]. Nowadays most of qanats shown in figure 2 are dry and inactive, except Pachenar and Ghasem Abad qanats that they are still active. There is a high density of qanat chains in the developing western part of city with high buildings. Ground settlement will be induced by qanat collapse in these areas due to structure loading and may cause some damage to structures and lifelines. On Andishe Street in Ghasemabad area (west of Mashhad) several ground settlement took place. Most of this damage is due to construction over hidden tunnels and access wells of old qanats [8].

Characteristic of qanats in zone 11 of municipality of Mashhad

Study area lies between Chehelbaze floodway from the north, Azadee highway from the east, Vakilabad Boulevard from the south and Namayeshgah square from the west. Statistics show that 170941 people lived in this area in 1386. This population makes up 7.04% of Mashhad population. Zone 11 is not an old region in Mashhad but it grew rapidly in recent years. Urban aerial photos with 1/6000 scale in 1351 was used to determine the exact location of qanats in study area. Water-resources map of Mashhad plain that supplied in 1343 indicates 9 main qanat chains exist in study area their characteristics is shown in table 1 (khorasan Razavi Regional Water Company).

Due to decline of groundwater level in Mashhad plain, many of these qanats are dry except Ghasem Abad qanat that recharge from mountain. Qanats in table 1 checked with qanats were seen in aerial photos. 31% of qanat shafts have 15-30 meters depth that located in the east of study area. 1.2% of them have less than 15 meters depths that belong to Ghasem Abad qanat

and the others have more than 30 meters depth. Groundwater level map were drown to exploring the water table in study area and checking the depth of qanat gallery with water table (figure 3). Flow regime mainly is toward the west and topography slopes mainly is toward the east. In this area water level declined and it is between 60-90 meters from ground surface. Average depth of mother well in table 1 is about 60 meters so the location of water level is deeper than the depth of qanat gallery. So according this result the water table don't have direct effect in saturation of soil in tunnels and access wells of qanats and inducing the qanat collapse. There is not enough data about ground settlement in study area so we have to use of defective or incomplete data from fire services. Ground settlement was used to determine its relationship with qanat density. 7 cases of ground settlement happened in the study area during 1375-1386. In figure 4, black points are a sign of qanat shafts and grey rectangles are a sign of ground settlement. All of the ground settlement except one of them (85% of these cases) located in area with high and very high density of qanat. Therefore we can conclude that the ground settlement occurrences are influenced by qanat density in study area. One of the main reasons of ground settlement is the qanat shafts and wells that filled with earth fill soil and fill material. In past years the soil mechanic tests did not carry out and construction done on the earth fill soils with low relative density and low shear strength. So nowadays, urban problems like ground settlements occur in these areas.

Collapse hazard map

Numbers of qanat shafts per area and land use are two factors that evaluated for qanat collapse zonation. Land use planning is the most important factors in control and management of urban project and it determines how to use of land with the mention of urban necessity [9]. The most hazardous area in this region is defined as blocks with an area of about 10000 m^2 that contain more than three qanat shafts. It is apparent that the blocks without qanat shafts don't have the collapsibility potential. Finally the region under study is classified into 3 risk groups according to land use such as

1) Low risk area. 2) Medium risk area. 3) High risk area.

High risk area consists of residential areas with buildings that have more than 3 floors and also schools, hospitals, governmental buildings and historic-cultural centers. Highways and residential areas with medium density are classified in the second group. Low risk area includes residential areas with low density and green areas. Figure 5, shows the qanat collapse map of the region based on land use and qanat shaft density. Different classes that are shown in this figure are as follows:

Class 1: No qanat shaft + low risk and medium risk and high risk.

Class 2: 1-3 qanat shafts + low risk.

Class 3: More than 3 qanat shafts + low risk.

Class 4: 1-3 qanat shafts + medium risk.

Class 5: 1-3 qanat shafts + high risk. Or More than 3 qanat shafts + medium risk.

Class 6: More than 3 qanat shafts + high risk.

Based on the results obtained, about 28% of the region belongs to class 5 and 6 where the highest potential of collapsibility is expected. Moreover qanats located on northwest of the study area are less than 15 m deep so the collapse and induced settlement is more probable. Also some foundational settlements have shown in this region.

Conclusion

Qanats were a sign of genius at hydraulic science that used by Iranians over centuries; but nowadays they have made problems in urban area. There is not exact location map of qanat in Mashhad and almost always the qanat location was ignored in urban project. The problem is doubled in developing part of city like west areas because of high buildings and high density of qanats in those areas. Most of qanats in Mashhad area are dry and the access wells of old qanats were filled by earth fill soil; as a result the qanats have disappeared over the years. Due to structure loading and ground water changes, their stability may be altered and collapse would occur. 2355 qanat shafts were fined by using aerial photos in study area. On the other word there is a qanat shaft instead of 70 inhabitants in this area; or there is a qanat shaft in each 7000 m^2 area of zone 11. In Collapse hazard map of study area more than One-fourth of lands have a high risk of qanat collapse. 85% of land subsidence located in area with high and very high density of qanat. We suggest preparing a qanat location map in urban area. This map will be used in management of land use and urban development. Another suggestion is to use the geophysics methods for finding the disappeared qanat location.

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Table 1- zone 11 qanat chains characteristics visited in 1342 (khorasan razavi Regional Water Company)

Qanat name	Mother well depth(m)	Qanat length(m)	discharge (L/S)
Absarde or sad abad	65	11000	45.7
Farah abad	71	6100	42
Neka	90	18000	8
Mil kariz	80	13000	dry
Sanabad	65	7000	9.4
Nohkodak	75	17000	52.59
Ghasem abad	43	2300	15.2
Malek abad	80	8500	84

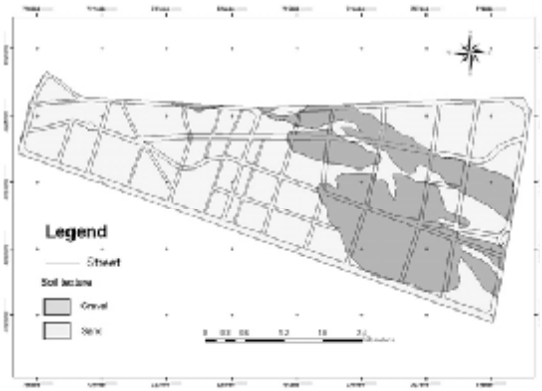

Figure 1- surface soil type map of zone 11 of municipality of Mashhad

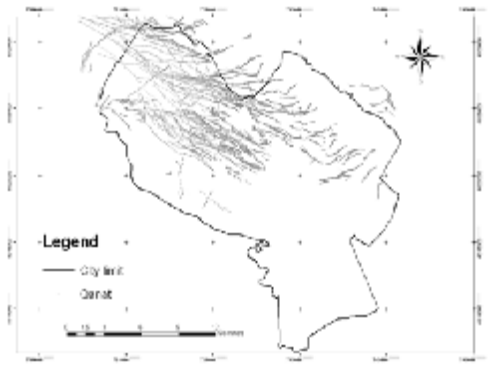

Figure 2- qanat map in Mashhad area

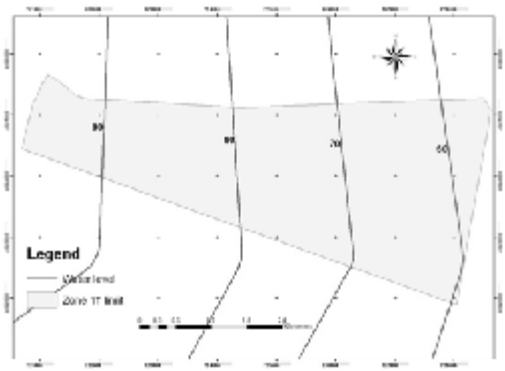

Figure 3- groundwater level map

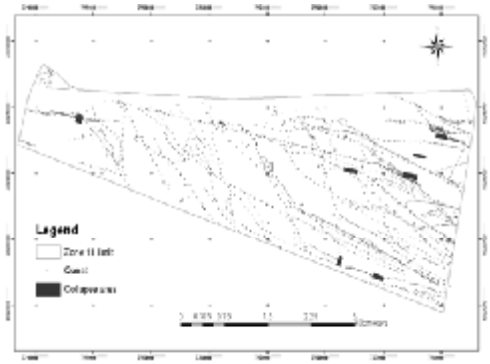

Figure4- ground settlement map of zone 11 of municipality of Mashhad

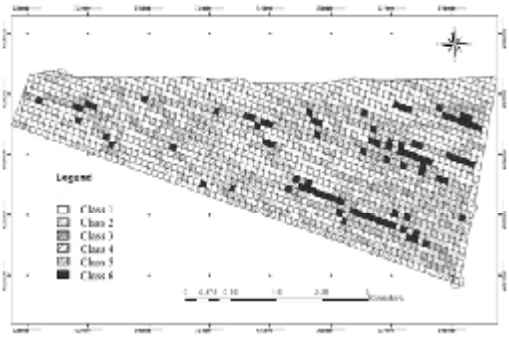

Figure 5- collapse hazard map of zone 11 municipality of Mashhad