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Planning Crisis Management of Water Resources in Tehran in the Next Twenty Five Years

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ABSTRACT

Daily consumption of 3.2 million cubic meters of water in the city of Tehran causes not only planning problems (estimation of demand and supply) and excessive costs to supply and transfer water. It also endangers the environment. In addition, it is not compatible with sustainable development. Global warming and the fact that the climate in Iran and specifically Tehran is turning hot has bought water crisis to this city. Considering that the Per capita daily water consumption in Tehran is three times as much as the international standards, the crisis seems to be more serious than water rationing such as the one implemented in the summer of 2014.This paper, aiming to plan to control this crisis, predicted precipitation in Tehran in the following 25 years by means of SDSM Model. Then, the amount of rainwater harvested in the city passages and the roofs was estimated and economically analyzed. Saving 20 percent of the water needed by the city, and an average decrease of 57 million dollars annually to supply and transfer water in Tehran by means of rainwater harvesting could be a management strategy to control the present crisis and the ones ahead.
KEY WORDS: water resources Management, sustainable development, climate change, rainwater harvesting, water crisis, SDSM, predicting the amount of precipitation, drought.

1 .INTRODUCTION

The total water consumption in the province of Tehran was as big as 980.73 million cubic meters in 2008 [1].Not surprisingly, the per capita daily water consumption in Tehran is 320 liters which is twice as big as the international standard. This figure is between 200 to 250 liters in the cold winter while it rises to up to 370 to 400 liters in the summer and peak times which is 2.5 or 3 times as big as the international standard [40]. In hot days of the summer of 2014, water consumption in the province of Tehran rose to 4.2 million cubic meters per a day 3.2 million cubic meters of which belonged to the city of Tehran. In other words, monthly water consumption in the city of Tehran equals the capacity of a Rutland Water (one of the largest artificial lakes in Europe).

The decrease in the water of supplying dams, hot weather, drought, water shortage, and reduction in precipitation over the last few years in the city of Tehran [3], and the fact that there was a warning saying that fresh water might be rationed in the summer of 2014 signify water resources crisis in this city which demands finding solutions.

As long as surface and underground water resources consumption goes on as intensely as now, there will be no water for the next generations as well as hard times in the years ahead. The significance of environment conservation leads Tehran to take advantage of sustainable development in water resources. Hence, considering global warming and the fact that Iran is going to suffer shortage of water and drought [4,5], environment and water supply managers are required to well understand the capacity of water resources of the country in the following decades. Knowledge of the capacity of the future water resources will lead to acceleration and precision in planning and management of water crisis.Regarding the political, geographical, and social significance of Tehran, this research tried to precisely analyze the recent water crisis of the city, and to provide solutions to tackle the present challenge following sustainable development in water resources planning and management. To do so, initially, Global Circulation Models (GCM) and SDSM were used to predict the precipitation in Tehran in the next twenty five years. Then regarding the amount of the precipitation, the analysis of the surface water resources was done.

The present paper includes seven sections. The review of literature of water studies is presented in section two. Section three introduces Tehran. Modeling of predicting the amount of precipitation and its analysis is

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discussed in section four. Methods of rainwater harvesting are presented in section five which is followed by conclusion.

2 .REVIEW OF LITERATURE

A lot of research has been carried out in water resources management. However, application of sustainable development approach in such research is not observed much. Research related to the present study could be categorized into recycling and water quality control, management of surface and underground water resources, precipitation and runoff prediction, downscaling methods, the study of climate change, rainwater harvesting methods, and so on.

Climate change could cause frequent meteorological events such as flood and drought [6]. Climate change studies mostly focus on a specific area, and mainly the concentration is the catchments due to their importance. In studies of climate change, GCMs are used to observe the influence of climate change in surface and underground water resources [7]. Downscaling methods along with climate change studies and GCMs are used to turn weather variables from large scale to local scale [8,9].The change of land cover from pervious area into impervious area in urbanized areas leave an impact on the increase of runoff depth and directly will cause flood and inundation area [10].Rainwater harvesting is considered as an alternative to tackle water shortage. This is done with a specific purpose and application [11]. This can be regarded as one of the plans in water resources management [12]. One of the most important subjects in rainwater harvesting is the study of its effect on river basins. Rainwater harvesting is the collection and use of surface runoff up the river basin [13].Recent studies of planning and management of water resources, reviewed in this paper, could be categorized as shown in table 1.

Table 1. Classification of former studies

N.O	fields of Study	Purposes	Reference
1	water recycling and quality control	Water recycling and reuse	[14,15,16]
		Water quality control	
2	water resources management	Surface water	[2, 4,7, 17,18, 19, 20, 21, 22, 23]
		Underground water	
		Study of the rate of population growth	
		Method of supplying water	
		integrated water resources management	
		Simulation and optimization modeling	
3	Predicting the amount of precipitation	Precipitation prediction	[8, 9,10, 11, 24 , 25, 26, 27]
		Runoff models	
		GCMs	
		Downscaling methods	
4	Climate change	Temperature changes	[6, 7, 18, 24, 25, 26, 27, 28]
		Drought	
		Flood	
		GCMs	
		River basins	
5	Rainwater harvesting	Rainwater harvesting methods and systems	[12, 13, 15, 29, 30, 31, 32, 33, 34, 35]
		Rainwater consumption	
		Types of rainwater consumption with details	

The present research, considering the fields of climate change, precipitation prediction, water resources management, and rainwater harvesting, was a comprehensive study which analyzed rainwater harvesting as a management solution to control water crisis in Tehran from an economical viewpoint.

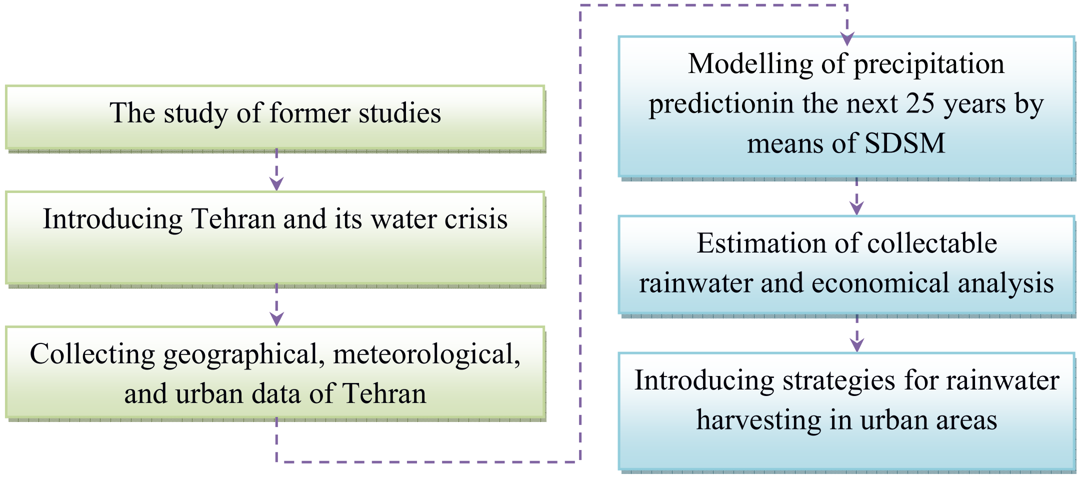

Figure 1.Research process diagram

3 .Introducing Tehran

The province of Tehran has a population of 12.425 million people with almost 8.25 million living in the city of Tehran. This city is the 25th most populated city in the world. It is also 27th largest city with a size as large as 730 square kilometers. It is surrounded by mountains in the north, and desert in the south. Consequently, it enjoys different climates in the north and the south. The north has a cold and dry climate and the south has a hot and dry one. The main source of precipitation is the wet Mediterranean and Atlantic winds which blow from the west. The annual precipitation in Tehran, which is mainly caused by differing heights around the city, ranges from 422 millimeters in the north to 145 milliliters in the south-east [1]. Decreasing annual precipitation could be the sign of climate change in the city which is turning to a hot and dry one.

Water resources in the province could be categorized into surface and underground resources. Underground resources could be used by means of springs, qantas, or wells. Hable-rood, Abhar-rood, laar, Jaj-rood, the river of Talegan, and the river of Karaj include the most important surface currents. According to the data on the website of Tehran water and wastewater company [40], the reserve of the water in the four dams of Latian, Talegan, Amirkabir, and Lar in 2013 decreased by 200 million cubic meters in comparison to the one in 2012. The map of Tehran and its water resources are shown in figure 2. The red line demonstrates the border of the city of Tehran. Main types of land use pattern in Tehran are shown in table 2.

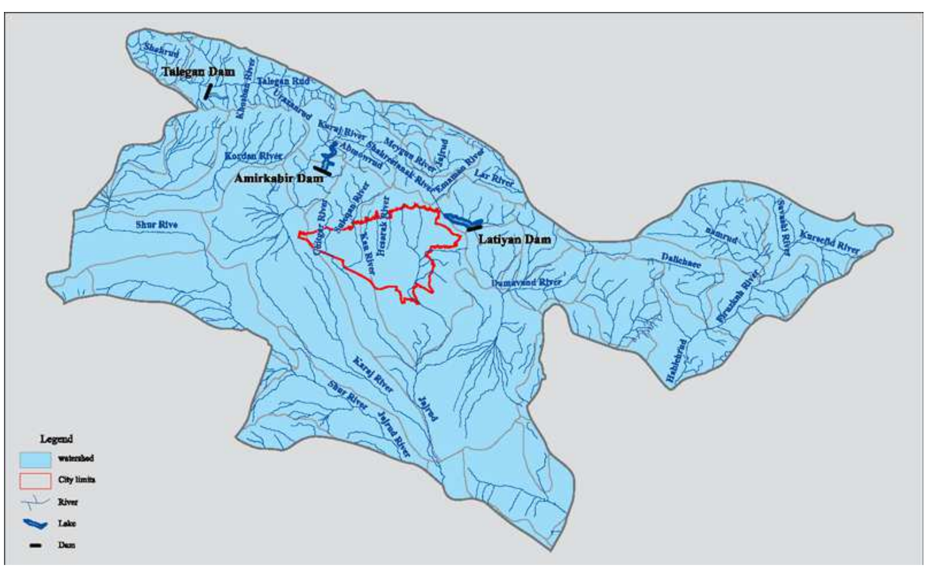

Figure 2. Tehran province watersheds [1]

Table 2. Occupied area and proportion of main land use kinds [1].

No.	Type of Landuse	Occpied Area (km^2)
1	Residential	177
2	Commercial-Administrative	26
3	Industrial-Manufactory	27
4	Transportation &Warehousing	30
5	Pass way & access network	114
6	Urban services	50
7	Green space	70
8	Agriculture	35
9	Military	44
10	Not built	41

The ones in row 1 to row 3 from table 2 belong to roofed buildings which totally amount to 230 Km^2. A part of row 4, 6, and 7 are also roofed buildings which approximately amount to 70 Km^2. Therefore, the area of all the roofs which could collect rain in the city equals 300 Km^2. Row 5 is the area of the passages in the city (114 Km^2). The surface rainfall in the city passages is led to the waste water treatment, waste water network, or out of the city by means of the channels collecting surface water. While this water resource is so valuable, it is usually neglected and not used. However, with planning and appropriate management, it could be used optimally or at least it could be led to specific places to join underground water resources.

4 .Modelling of precipitation prediction

Many states and international organizations tend to predict climate change so as to predict events such as flood or drought by means of modeling. Predicting climate change has economical, social, and environmental applications.

One way to predict climate change is to use the outputs of GCMs. However, due to the large size of the networks of GCM, it is not applicable in regional and local studies. When downscaling and predicting climate variables, different scenarios with different climate, economical, and social viewpoints are used. For instance, a viewpoint could be about global warming. In other words, global warming is on the increase, and it is seemingly related to the changes in the atmosphere and climate changes. Events such as droughts, unexpected floods, sudden cold or heat wave are the consequences of climate disorder which is leading the world climate to unexpected situations. Another one is emission scenario. It says that the economical growth in societies and development of industries have helped emit carbon monoxide and the other pollutants. In other words, emission of greenhouse gases in industrial sector has been accelerated in the recent years, and energy consumption in emissions in non-metal mine industries are noticeable [36]. Another scenario could justify the reduction in the emission of carbon monoxide. For example, pollution prevention (PP) is an effective way for the factory production process that does not have any significant waste and inefficiency [37].

There are different ways to generate climate scenarios. However, which one makes more reliable predictions is not clear. One of the most simple but very practical one is regression method. The statistical method of downscaling is superior to with dynamical methods especially when lower costs and faster evaluation of factors influencing climate change are required.

Wilby et al (2002) made the first computerized model called SDSM to do downscaling by means of multivariate linear regression [38]. In regression models, data from National Center for Environmental Prediction (NCEP) interpolated on the network of coupled general circulation model (CGCM) is used for the calibration and evaluation of downscaling.

The present study took advantage of SDSM which consists of three main stages namely calibration of the model, evaluation of the model, and generating meteorological data. Initially, the capability of this model was evaluated and calibrated with the observed data from synoptic station of Mehrabad Airport in Tehran over a thirty-year period (1975- 2005). The evaluation of the model was executed by comparing the charts of the statistical period data and the data generated by the model. Mehrabad Aiport station was chosen to study as it is approximately located in the city center. Finally, precipitation in the city of Tehran for a twenty-five year period (2016-2040) was predicted. If the predicted precipitation is multiplied by the area of the roofs in the city (300 Km^2), the average of the rainwater collectible from the roofs could be obtained. The amount of the surface water in the city passages could be estimated likewise. The details are briefly provided in table 3.

Table 3. Precipitation and related calculations

Year	Rain (mm)	Roof Water (m3)	Pass Way (m3)	Sum (m3)	Squander ($)
2016	415	124500000	47310000	171810000	65287800
2017	422.4	126720000	48153600	174873600	66451968
2018	285	85500000	32490000	117990000	44836200
2019	339	101700000	38646000	140346000	53331480
2020	**363**	**108900000**	**41382000**	**150282000**	**57107160**
2021	370	111000000	42180000	153180000	58208400
2022	373.2	111960000	42544800	154504800	58711824
2023	352	105600000	40128000	145728000	55376640
2024	410	123000000	46740000	169740000	64501200
2025	402.5	120750000	45885000	166635000	63321300
2026	297.6	89280000	33926400	123206400	46818432
2027	319.4	95820000	36411600	132231600	50248008
2028	384.6	115380000	43844400	159224400	60505272
2029	385	115500000	43890000	159390000	60568200
2030	341.2	102360000	38896800	141256800	53677584
2031	353	105900000	40242000	146142000	55533960
2032	418.7	125610000	47731800	173341800	65869884
2033	360	108000000	41040000	149040000	56635200
2034	261	78300000	29754000	108054000	41060520
2035	297	89100000	33858000	122958000	46724040
2036	335	100500000	38190000	138690000	52702200
2037	285	85500000	32490000	117990000	44836200
2038	300	90000000	34200000	124200000	47196000
2039	418	125400000	47652000	173052000	65759760
2040	379	113700000	43206000	156906000	59624280
Total	**8866.6**	**2659980000**	**1010792400**	**3670772400**	**1394893512**

As mentioned earlier, climate change caused by global warming and a tendency to drought has decreased precipitation. This is observable in graphoffigure 3. This graph demonstrates the amount of the annual precipitation predicted for Tehran for the next 25 years. Considering the descending line fitting in the graph, the annual precipitation in the city is decreasing with a slope of 1.7 which signifies a decrease in the precipitation by 2040 in Mehrabad station.

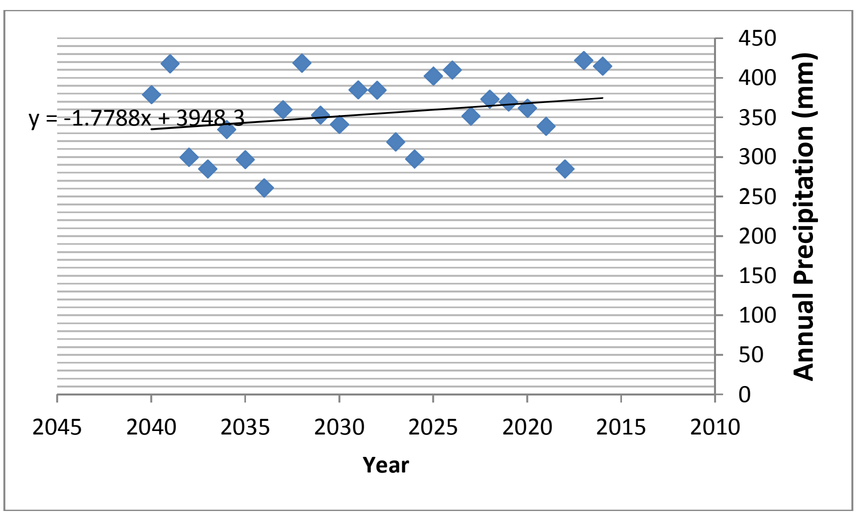

Figure 3. Prediction of the amount of the annual precipitation in Tehran by 2040

As shown in table 2, nearly 150 million cubic meters of water could be harvested in 2020 from the buildings and passages in Tehran. The runoff in other parts of the city such as the green spaces or the otherwise is stored as underground water. The rainwater in the passages and the roofs unlike the other runoffs in the other parts of the city could easily be managed. In other words, if this is not purposefully managed, 150 million cubic meters of usable surface water will be wasted in 2020 and the other years. If it is used in green areas of the city, agriculture, and especially in homes (toilets, cleaning, gardening, heating and cooling, etc), it will be a considerable percentage of the annual water supply of the city namely 15 to 20 percent. This will also decrease the costs of water transfer and supply. According to the information on the Tehran Water and Wastewater website in 2014 [40], the citizens pay 0.11 $ (3000 Rial) for a cubicliter of water while the cost (harvesting, purification, transfer, distribution) equals 0.38 $ (9000 Rial) for the government. By harvesting rainwater, 57 million dollars will be saved to supply water for Tehran, regardless of the annual rise in water price. Considering the average price of 1.5 $ for a cubic meter of water in Europe and the USA and the annual rise in water price, the figures in the above table will be astrological. Apparently, rainwater harvesting requires necessary infrastructure and investment. However, creating such infrastructure will help harvest rainwater for a long time (as long as a dam's lifetime). This is the main reason why such projects are technically and economically feasible. Moreover, rainwater harvesting will be socially and politically justified for any country.

5. Strategies to harvest rainwater

In this paper, projects of rainwater harvesting are categorized into urban and non-urban. In the urban section, rainwater in the passages is harvested by creating canals leading the surface water. In buildings, this is done by installing devices in the roofs. In addition, in open spaces and green spaces, specific harvesting methods are used to harvest rainwater. In the non-urban section, there are artificial watershed projects which will be mentioned later.

As observable in table 3, the precipitation distribution of Tehran in the next twenty five years, after long years of drought, there will be a lot of rain in many cities which will fill in the wells and aquifers causing development in agriculture. However, most of the aquifers will be at risk of extinction. The precipitation will not have been good enough to restore them. Despite good precipitation, due to lack of necessary equipment to store rainwater and floods, a lot of this will go into the sea directly and be wasted. Steep land, flood rains, lack of dams and catchments, and watershed projects not being executed in many areas generally will cause rainwater not to have any chance to fill in aquifers. In addition, in practice, a large amount of water sources created by heavy rain will be lost on plants and aquifers, and wasted (like the aquifers in Kangan in 2013). It needs to be mentioned that over many years, due to building roads, transferring gas pipes, developing urban areas, overusing the aquifers and wells, manipulating the ecosystem, non-technical excavation and earthwork, and lack of dams, catchments and desalination systems, most of the aquifers geting salinated will dry up (such as aquifers of 90 percent of the wells in Kangan).

When the water of a well becomes salty, it will not get back to the previous state even if there is a lot of rainfall and even if the aquifers are full. One of the best solutions is execution of watershed projects in the area. If precipitation is slow and mild, it will gradually get into the earth. Then, the earth will have the chance of absorbing the water. This will greatly improve the underground water. Creating small pools and catchments will stop earth from eroding, and water from penetrating into land.

The growth of population, industrialization, and agriculture, promotion of human life quality, increasing consumption of water, water pollution, and also climate change are the main causes of water crisis in many countries including Iran. Under these circumstances, rainwater seems to be the best alternative for water. Rainwater has advantages over other resources. Moreover, rainwater harvesting could help control flood currents in regions where there are showers and floods [35]. What needs to be taken into account is that it cannot be executed in all agricultural sections and industry. It depends on the hydrological and climate conditions of the region.

It should also be mentioned that widespread application of rainwater harvesting requires penetrability and improvement of land in a large scale which might put feeding of the aquifers into more serious trouble than the plight they are in now.

However, it could be more applicable in gardening and some other small scale activities. It must be admitted that rainwater harvesting could not gain as much water as a well's. In addition, the time of rainfall does not often overlap with the time plants need irrigation. Therefore, if rainwater harvesting is done to put the water into use in irrigating plants, big tanks need to be provided to store the rain, and plans need to be made if it is supposed to be stored for a long time.

Rainwater harvesting through collecting areas is often done to help non-drinking home consumption, irrigating green areas, irrigating plants which need little water, and cultivation in the greenhouse. The term 'rainwater harvesting' was first used in 1963 by Gebbes [39]. Rainwater harvesting components consist of the following:

Catchment area: a part of the earth which leads all or a part of the rain to accumulate and go to the target spot. The target spot is usually away from the catchment area which is usually as large as a few square meters to several square kilometers. It could be a farm, a rocky area, or a marginal farm, and even a home roof or paved area.

Storage place: this place is a reservoir where a runoff is led and stored until it is used. It could be surface, underground such as cisterns or the free space in soil profiles or the alluvium at the bed of seasonal streams (in the form of underground dams).

Target spot: the place where water accumulated is consumed. In agriculture, the main purpose is to provide the plants and animal with water while in homes, it is to satisfy human needs.

5-1.Rainwater harvesting techniques in the city

Rainwater harvesting with buses: since the roofs of the inner-city buses make a large area and the fact that they run long hours in open spaces in comparison to other forms of transport, one of the fastest and most low-cost ways to supply irrigate green areas in the city could be installing tanks under the buses to accumulate the rain on the roof, to discharge and store at the terminal. The technique needs to be financially and technically justified.

Rainwater harvesting through the roofs of the buildings: there are different techniques designed and executed to harvest rainwater across the world. However, the main mechanism is to harvest rainwater through the roofs (especially in green buildings) by making them unpenetrable with certain material, and leading the water to the reservoirs by gutters and pipes. Along with theses components, there are others such as pumps, purifiers, lines connecting to the sewage and etc. Rainwater harvesting is highly justifiable in car-washes, fountains, and industries such as stone cutting factories. Figure 4 demonstrates a rainwater harvesting system through the roofs schematically.

Figure 4.Rainwater harvesting system in roofs

Rainwater harvesting in city parks: in parks, a hybrid system of rainwater harvesting and lighting production could be used. A system which makes water accumulation and purification in the least occupied space possible. This is how it works. Solar energy is received by the panels in the machine, and used in three different ways. One part is used as electrical energy to be used for lighting at night. Another is used to purify water. And the other part is used to supply cold and hot water. All this is done with solar energy. The tank for this system could be designed to have varied capacity.

Rainwater harvesting in open spaces: rainwater could be stored in open spaces by making ground impenetrable and creating small artificial catchments (proportionate to the size of the area). This water could be used to drip irrigate the plants in the area, or used otherwise. One of the applicable systems is the one called Watree innovated by Chris Buerchner. It looks like an inverted umbrella which could not only be used to protect people from rain. It could also be used to accumulate water. Figure 5 shows some types of rainwater harvesting schematically. As shown in the figure, the main mechanism in the systems is the presence of a water collecting surface. This surface could be roofs, solar panels, streets, and etc.

Another way to harvest rainwater is creating dykes in river routes, or places which are prone to flooding when rain falls. Artificial watersheds (pools and Cistern) play the same role. Underground dams are also another strategy to deal with drought.

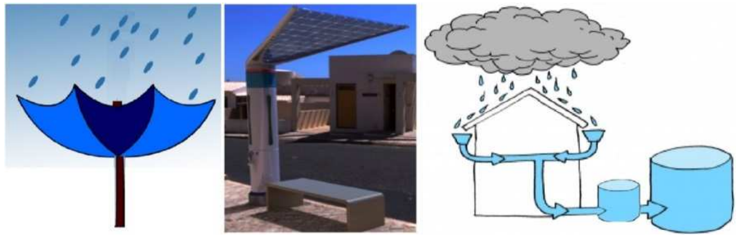

Figure 5. Schematic design of a few rain collecting surfaces

Conclusion

Climate change is at the center of attention in planning and management of water resources. The results of most studies of climate change signify an increase in the temperature of the Earth and a decrease in precipitation. A decline in the amount of the water in the dams, global warming, drought, shortage of water, and a decrease in the percentage of precipitation over the last years have brought about water crisis in the capital city of Tehran. Moreover, the Per capita daily water consumption, in this city in hot days of summer ranges from 370 to 400 liters a day which is almost three times as much as the international standards. Apparently, appropriate planning is a prerequisite for management of resources. To plan well, you need to have a precise understanding of the present conditions, those of the past and the future. Having this in mind and having collected the geographical and meteorological information of Tehran, this research predicted the precipitation in the city for the next 25 years by means of SDSM model. Then, taking into account the urban development data, the amount of rainwater harvestable in the city passages and the roofs was estimated. To economically analyze this, the value of rainwater harvestable in the city was estimated. As supply, purification, and transfer of each cubic meter of water to the city cost almost 0.38 dollars for the government, rainwater harvesting in rain collecting areas in the city (300 Km^2) helps save 150 million cubic meters which is 20 percent of the annual consumption of the city. This is an average annual decrease of 57 million dollars for the government to supply water. Rainwater can be harvested by varied systems installed in the roofs of buildings, public passages, parks, and open spaces in urban areas. In Non-urban areas, this can also be executed by watershed projects, dykes, and underground dams to deal with drought. Moreover, this can prevent floods caused by rain. Execution of rainwater harvesting systems could promote the culture of appropriate water consumption as well.

Future studies are suggested to focus on neighboring cities and provinces to plan optimal distribution of needed and excessive water using the data form synoptic stations around the city. It must be mentioned that the study of developing systems of water harvesting in urban passages and its necessary infrastructure in order to connect it to the city network seems to be fundamental and novel.

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