Water Harvesting and Groundwater Recharge in Arid and Semi-Arid Regions (Tehran Mega City's 2008 Water Crisis Challenges)

Fowad Vojdani
ABAZMA Strategic Water Research Center, Tehran, Iran

Abstract

Water is essential to life and this means that water has infinite value. Water is so clearly linked to our economic and social welfare, then how can water be priced so much lower than gems and gold, which while aesthetically pleasing, ultimately have no bearing on our ability to sustain life?

The vast arid and semi-arid regions of *Asia* and *North Africa* constitute 85% of the region's land area and are home to approximately 60% of the region's population. Limited water resources pose severe constraints to people's economic and social progress, testing their resilience and threatening their livelihoods. So, Water is becoming a cause of social conflicts.

Rainfall is not only scarce and unpredictable, but the region is also subject to frequent and severe droughts. Available surface water is declining and the over-pumping of groundwater beyond natural recharge rates is occurring, lowering the water table and causing an increase in groundwater salinity and ecological degradation.

Large numbers of population are living in the arid and semi-arid belts of the world where rainfall is limited and very irregular. Water harvesting is a proven technology to increase food security in drought prone areas. Erosion control and recharge of groundwater are additional advantages of water harvesting techniques.

The objectives of this paper are to discuss water harvesting effect on groundwater recharge especially in the arid and semi-arid regions, caused by:

1. Population growth and migration from villages to towns and from small towns to big cities (demographic structure).
2. Changes in life style and necessity of hygienic life.
3. Possible effect of climate change (however the detailed implications of climate change are not yet clear).
4. Location of the countries on the global map.

Meeting this increasing demand from existing resources including water is an uphill struggle, particularly in water stress/scarce regions in the world. It seems there are two potential responses:

- Either supply-side, obtain new resources to meet demands.
- Or demand-side, managing consumptive demand itself to postpone or avoid the need to develop new resources.

There is considerable pressure from the general public, regulatory agencies, and some governments to minimize the impacts of new supply projects (e.g. building new reservoirs or restoring floodplains, or inter-regional transfer schemes,…), implying the emphasis should be shifted towards water harvesting by best utilizing the water that is already harvested and is available in aquifer.

Introduction

The resources to supply the water needed for human consumption are divided in the two major groups of surface and ground resources. The surface resources include flowing waters such as rivers, streams, springs and brooks as well as still waters such as natural glaciers, seas, ponds, lagoons, etc.

Groundwater resources consist usually of aquifers formed by the infiltration of surface waters to the vacant spaces between the different layers in the soils and their accumulation through a centuries-long process.

Water extraction from ground resources, particularly in areas far from freshwater lakes and rivers, dates back to ancient times and the early civilizations, and one probable reason for settlement of early humans along large rivers and next to freshwater lakes might have been their difficulty on drilling wells and extracting water from the sustainable groundwater resources.
Nonetheless, those who due to natural and environmental conditions were forced to live away from safe and sustainable surface water resources, gradually learned to drill wells and extract water from the ground, thereby ensuring a secure water supply.

In arid and semi arid regions of the earth, where each drop of water is preciously vital, the availability of sustainable groundwater resources depends on two important factors:

1- The geological characteristics and natural conditions facilitating the creation of ground water resources, and
2- The possibility for natural and artificial recharging of these resources.

The goal of this article is to describe water harvesting and its implementation through examples from different parts of the world, ground water recharging and its various processes, ground water recharging by water harvesting, the importance of water harvesting for ground water recharging in arid and semi-arid regions of the world, the challenges of the 2001 water crisis in *Tehran*, the lessons learnt, and the positive impacts that water harvesting during the years 2001-2008 could have had on recharge of *Tehran* aquifer and the 2008 water crisis.

The methodology applied in this research included library research to collect data and documents around the world, in the region and in *Iran* and the internet web search, to supplement the long experience of the author during his career in *Tehran Water Sector*; and particularly the lessons learnt at the time of the 2001 crisis, when he was the Manager of the Bureau for Consumption Management and Reduction of Water Losses, and his more recent experience as the President of the *ABAZMA Strategic Water Research Center*.

In the end a conclusion is presented on the experiences of water harvesting in recharge of ground water resources in arid and semi-arid regions, and practical recommendations are provided for the benefit of other utilities in the world and especially in arid and semi-arid regions.

The global water situation:

Satellite photos of the earth show 2/3 of the planet covered by water, but it should not be forgotten that 97% of these waters are brackish and unusable, requiring considerable costs to desalinate, which are uneconomical and unaffordable by most countries.

Of the remaining 3%, which make up the total freshwaters, 2% are in the form of snow and ice in the poles and inaccessible cold areas, leaving les than 1% of the waters on earth as fresh and readily available. Therefore a global commitment for prevent the pollution and loss of this limited amount of freshwater coupled with its integrated management is a must.

This is the duty of international organizations such as the *United Nations* to remind the world of the importance of freshwaters and warn of the risks of pollution and loss of these waters, which are absolutely vital for the different wildlife species and the humans, and which directly affect the progress of societies, and through appropriate regulations, force governments to protect the freshwaters available in their states.

This surface and underground water is utilized for various human needs like agriculture, industry and urban use. This is why in arid and semi– arid countries, water is considered extremely valuable and they should pay considerable attention to protect and consume it efficiently.

What is the source of all water?

The source of all water is rain, of course**.** Supply comes from the sky, river water; water in lakes; ponds and wells; water that seeps into the ground; collecting in the belly of the earth; tap water; even bottled water! In order to meet demand, we actually need to harvest the rain and runoff. Not dam a river, and block its flow. Not boost water out the ground, and suck the earth dry. Not build canals, lay kilometers of pipes. But merely harvest the rain. In essence, harvesting water means harvesting the rain!

Definition of water harvesting

It means capturing run off or rain where it falls in the villages or towns, and taking measures to keep that water clean by not allowing polluting activities to take place in the catchments. Therefore, water harvesting can be undertaken through a variety of ways:

1. Capturing runoff from local catchments;
2. Capturing seasonal floodwaters from local streams;
3. Capturing runoff from rooftops;
4. Conserving water through watershed management.

These techniques can serve the following purposes:

- Provide drinking water;
- Provide irrigation water;
- Increase groundwater recharge;
- Reduce storm water discharges, urban floods and overloading of sewage treatment plants;
- Reduce seawater ingress in coastal areas.

In general, water harvesting is the activity of direct collection of rainwater, and the rainwater collected can be stored for direct use or can be recharged into the groundwater. Rain is the first form of water that we know in the hydrological cycle, hence is a primary source of water. Rivers, lakes and groundwater are all secondary sources of water.

In present times, we depend entirely on such secondary sources of water. In the process, it is forgotten that rain is the ultimate source that feeds all these secondary sources and remain ignorant of its value. Therefore, water harvesting means to understand the value of rain, and to make optimum use of the rainwater at the place where it falls.

Why to harvest water?

In areas where there is inadequate groundwater supply or surface resources are either lacking or insufficient, rainwater (or runoff) harvesting offers an ideal solution:

- Helps in utilizing the primary source of water and prevent the runoff from going into sewer or storm drains, thereby reducing the load on treatment plants.
- Reduces and controls the urban flooding.
- Recharging water into the aquifers help in improving the quality of existing groundwater through dilution.

How much water can be harvested?

Water Harvesting is a way to capture the rain water when it rains, or control flood and store these waters above the ground or charge the underground and use it later. This happens naturally in open rural areas. But in congested, over-paved metropolitan cities, we need to create methods to capture the rain water:

- The water harvesting basis: catch water where it falls.
- The water harvesting method: build systems that enable such an extension, and create a structure to manage the extension. These structures are eco-region specific.

- The water harvesting experience: millennial and born of local wisdom; scientific and still in use; participatory and the basis of people's movements; the focus of innovation in the present and the best way to a non-scarce future.
- The potential of rainwater harvesting: Understand by the water arithmetic.

Urban rainwater scenario

Urban centers are facing an ironical situation today. On one hand there is the acute water scarcity and on the other, the streets are often flooded during the rainfall. This has led to serious problems with quality and quantity of groundwater.

The total amount of water that is received in the form of rainfall over an area is called the *rainwater endowment* of the area. Out of this, the amount that can be effectively harvested is called the *water harvesting potential*.

Water harvesting potential = Rainfall (mm) x Collection efficiency

The *collection efficiency* accounts for the fact that all the rainwater falling over an area cannot be effectively harvested, because of evaporation, spillage etc. Factors like runoff coefficient and the first-flush wastage are taken into account when estimated the collection efficiency.

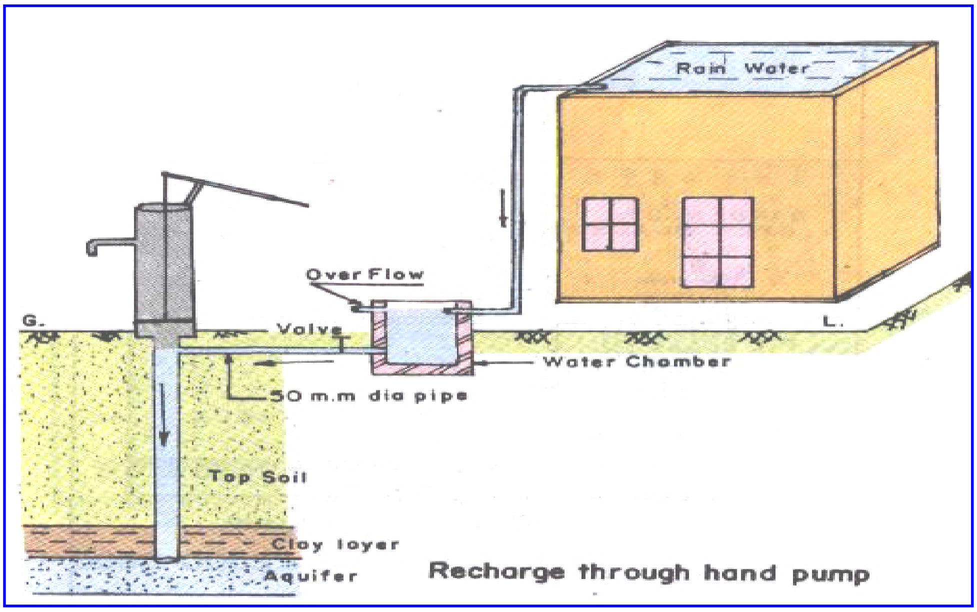
The following is an illustrative theoretical calculation that highlights the enormous potential for water harvesting. The same procedure can be applied to get the potential for any plot of land or rooftop area, using rainfall data for that area.

Consider your own building with a flat terrace area of 100 sq m. Assume the average annual rainfall in your area is approximately 600 mm (24 inches). In simple terms, this means that if the terrace floor is assumed to be impermeable, and all the rain that falls on it is retained without evaporation, then, in one year, there will be rainwater on the terrace floor to a height of 600 mm.

1. Area of plot = 100 sq. m. (120 square yards)
2. Height of the rainfall = 0.6 m (600 mm or 24 inches)
3. Volume of rainfall over the plot = Area of plot x height of rainfall
4. Assuming that only 60 per cent of the total rainfall is effectively harvested
5. Volume of water harvested = 36,000 liters (60,000 liters x 0.6)

This volume is about twice the annual drinking water requirement of a 5-member family. The average daily drinking water requirement per person is 10 liters.

The present design of the house will take all the rainwater from the roof and all the ground level areas surrounding the house and flow the water towards the street. (Where it floods the street, clogs the storm drains and sewer lines for a few days, before flowing away as sewage water).



Rural rainwater scenario

A “catchment” is any large surface that can capture and/or carry water to where it can be used immediately or stored. All open spaces are ideal spots for collecting rainwater. Instead of causing instant floods, flooding storm drains and sewage pipes that are blocked with junk, we can provide simple ways to re-charge the underground with rain water

Water situation in Iran:

Iran is located in the semi arid and water scarce regions of the earth. The existence of two vast deserts (*Loot* and *Namak*) has led to the aridity of the central plateau of *Iran*. This condition has created an arid climate condition in Iran. Therefore 85% of the country is composed of arid and semi-arid regions while only 15% benefit from a Mediterranean climate.

As for precipitation, *Iran* is also counted as a low-rainfall country. The average annual precipitation in *Iran* is approximately 250 mm, or equivalent to 1/3 of the world average, thereby justifying the necessity of an integrated water management in the country. Figure1 shows a comparison of average precipitation in *Tehran*, *Iran* and some continents and the world.

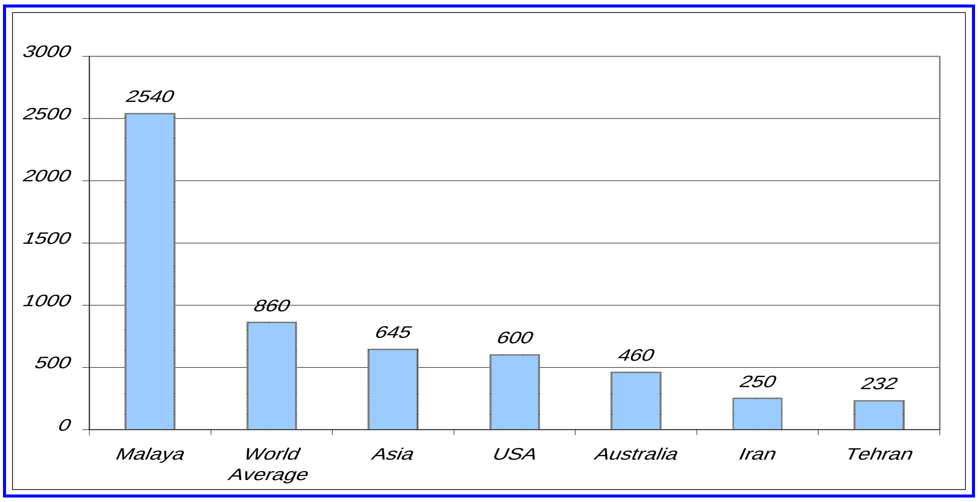


Figure1: Average of precipitation in different locations of the world

Countries like *Iran*, which from climatic and geographic point of view, are located in arid and semi-arid regions of the world, since they are in permanent water crisis condition, must reciprocate by concentrating on research, pure studies and also utilizing their utmost efforts to utilize water as much as possible optimally and manage their water consumption.

Average annual rainfall in *Iran* as have shown in above diagram is about 250 mm which is 40% less than average annual rainfall of *Asia* and 29% less than average annual rainfall of the whole world.

On the other hand, the increasing population has had a toll on the per capita renewable waters in *Iran* and *Tehran*. This has had a negative impact on agriculture and the sustainable development of the country, showing its unpleasant effect to the full during droughts. Figure 2 shows the decreasing trend of per capita renewable waters in the country and *Tehran* during the years 1956 to 2006:

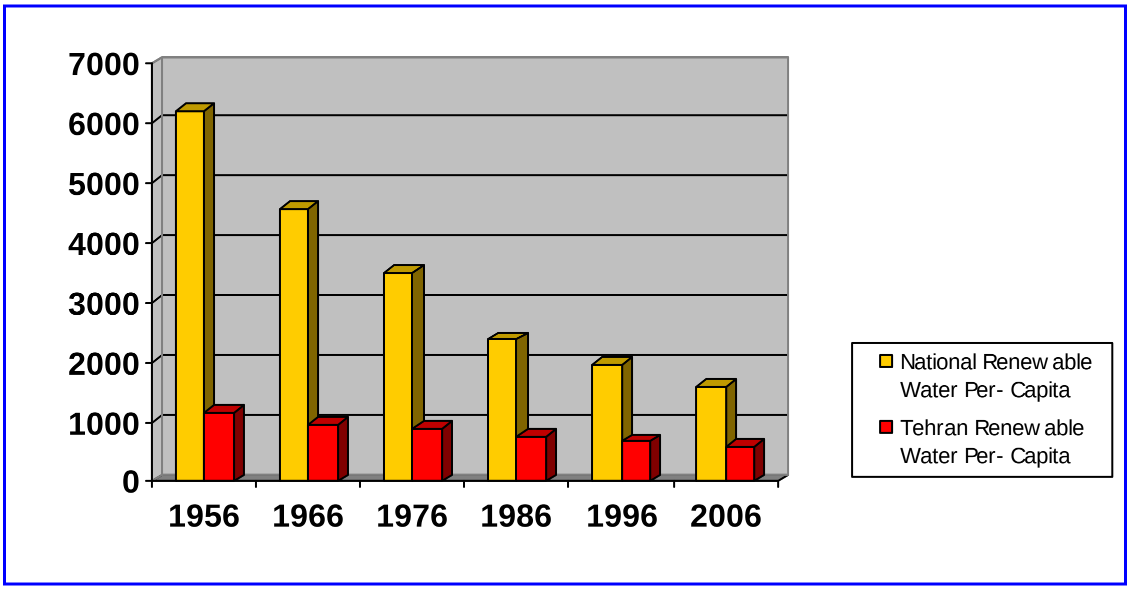


Figure2: National and *Tehran* decreasing trend of renewable waters per-capita (1956 – 2006)

Water situation in *Tehran*:

Major cities and capitals are historically formed along the banks of large rivers. However, given the fact that *Tehran* was originally not planned as a capital, it was not founded along a river, and when it was eventually selected as the capital, water had to be supplied from surrounding rivers and long distances. So it can be said that, there was no intention to turn this sleepy village at the foothills of *Alborz Chains* into the most important capital of *Middle East*.

Although, the Capital city of *Iran* enjoys having various surface and underground water resources, and also so called scattered and undirected water resources such as *Qanats,* springs, treated waste water, etc., Since, it is located on the fringe of two deserts (*Loot* and *Namak*), still adding all these resources together, they can't quench its thirst.

Average annual temperature and rainfall, and also explosive rate of population migration to this Megacity, are main reasons of existing and widening gap between supply and demand.

As population increased, the rivers became gradually inadequate to meet demands in *Tehran* and finally in the year 1964 groundwater basins had to be tapped to supplement supplies, reaching to the present point, when around 37% of the water needed by *Tehran* residents is supplied from these resources.

Based on statistical data, Tehran experiences drought and wet periods every 5-6 years. Figure 3 shows the 60-year precipitation trend in *Tehran*:

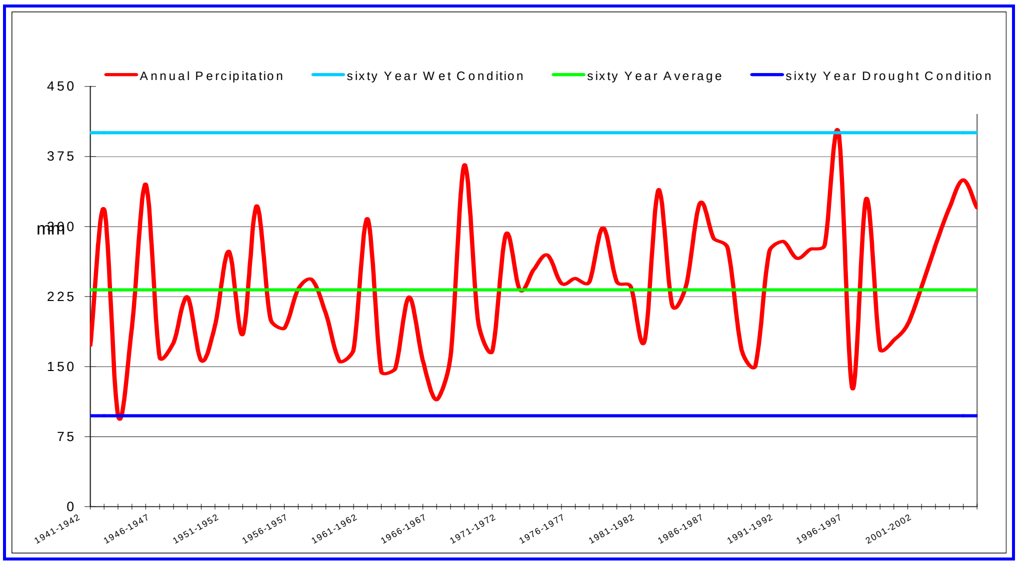


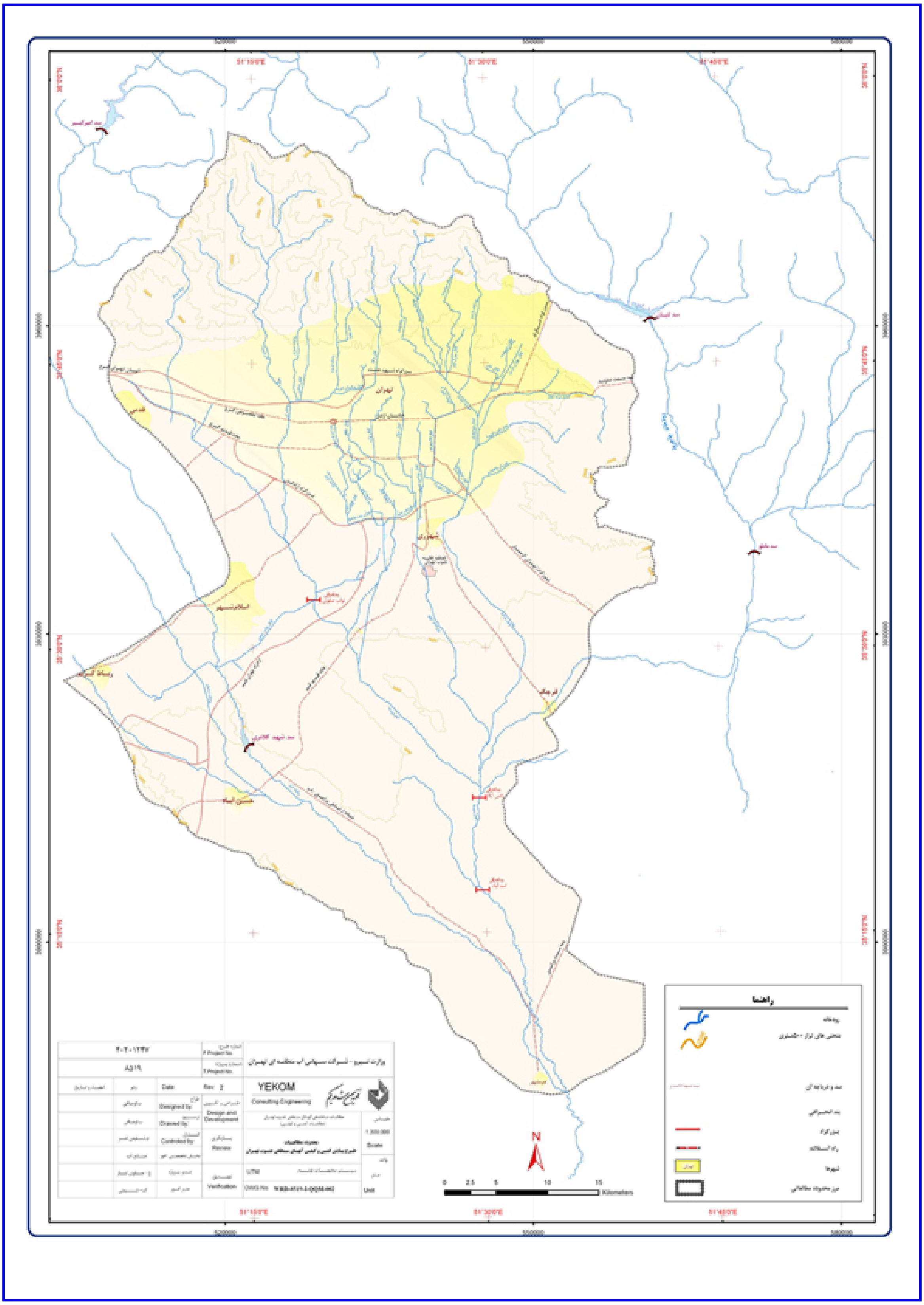
Figure 3: *Tehran* annual precipitation trend with 60year average precipitation

In the year 1992, trough the maximum use of surface resources' potential and permitted limit of withdrawal from groundwater resources, water supply and demand were balanced out, while during droughts, when intake from surface resources became limited, the officials were forced to compensate for the shortage from groundwater, which led to the rapid depletion of *Tehran's* aquifer, removing any chance of recharge during wet years. Consequently this situation has resulted in a significant drop in groundwater tables making the artificial recharge an inevitable necessity.

From the geographical, topographical and climatic aspects, *Tehran* is constantly threatened by water crisis, and since the maximum potential of surface waters and permitted withdrawal limits from ground waters has been reached, the only solutions to save *Tehran* growing population and immigration are:

1- Controlling population growth and preventing further migration to *Tehran*.
2- Preventing water losses in the production and distribution networks.
3- Public education and implementing consumption management strategies.
4- Collection and storage of rainwater and surface runoffs in multipurpose ponds for reuse as necessary.
5- Artificial recharge of the groundwater basins by flood and storm water.
6- Collection of urban runoffs and their storage and reuse before further pollution.

Tehran is located at the foothills of *Alborz Chains* and on a north-south natural slope, This topographic characteristic will assist the collection of water from streams and urban runoffs through new treatment processes in multipurpose ponds for amenities such as recreational and sport activities, forestation and green space irrigation, as well as for artificial recharge of *Tehran Aquifer*. In this way, there will not only be a compensation for the drop in groundwater tables, but it would also ensure the increase of pumping capacity during drought seasons. The following map shows the natural slope in *Tehran* as well as its rivers and runoffs.



Droughts experienced in the years 2001 and 2008 underline the necessity of the new approaches for water resources management and the storage of rainwater. Although there are two national plans for collection of storm water in *Tehran* and lowering the groundwater tables in the south of Tehran under implementation by two separate organizations, but despite heavy expenditures, they do not benefit from the necessary coordination and integration as a water harvesting plan. Furthermore after the completion of the *Tehran Sewerage* project and elimination of absorption wells, the opportunity for recharge of *Tehran* aquifer by wastewater potential would also be lost, thereby removing any chance of sufficient water supply for its replenishment. Therefore the *Tehran* metropolis still lacks an efficient executive plan for groundwater supply, and if the above projects are not implemented in an integrated manner, *Tehran* would face an even greater crisis during future droughts.

History of water harvesting in *Iran*:

Iran is an ancient land with a civilization history dating back to thousands of years and centuries before the birth of *Christ*. Like many other civilizations, our ancestors had their own particular techniques and technologies for supply and conveyance of their needed water, some of which are quite unique and only to be found in this land. *Qanats* are shining examples of *Iranian* ingenuity in transferring water from foothills to the dry and waterless territories.

Water harvesting is one of the oldest known gardening methods, dating back to the beginnings of agriculture. Water has been harvested in *Iran* since antiquity, with our ancestors perfecting the art of water management. Our ancestors had learnt to harvest water in various ways:

- They harvested the rain drop directly from rooftops.
- They collected rain water and stored it in artificial pool *(Estakhre*).
- In their courtyards, from open community lands, they collected the rain and stored it in artificial wells.
- They harvested water from flooded rivers.

Traditional methods

Public water supplies traditionally have been drawn from surface or groundwater sources, and treated and distributed by local water supply utilities (regional solutions). *Khazaneh* or *Khazineh*, which were artificial pond to restrain seasonal floods and to collect rainwater for use during dry summers are among other achievements of ancient Iranians.

In many old provinces and cities of *Iran,* such as *Bushehr*, *Kerman*, *Rey*, *Shiraz* and the northern provinces of the country, *Estakhre* was another encounters structures and monuments used by our ancestors to harvest, store and reuse rainwater for irrigation or to recharge the groundwater basins.

In addition to storage and artificial recharge of ground basins, ancient Iranians had invented other effective and ingenious methods for irrigation, which included earthenware urns (trickling jars) called *Tanbousheh*. These were placed under a tree for water storage and drip irrigation.

Modern methods

To address the challenges of water security in the new millennium, a mixture of traditional wisdom and new techniques must be employed. Decades of population and economic growth, emerging regulatory demands, and other pressures have led many water professionals to the conclusion that regional approaches might provide opportunities where utilities can pool their efforts with neighboring systems to develop more reliable water supplies, facilitate compliance, or gain appreciable efficiencies.

One of the purposes of this paper is to recognize the ways in which “regional solutions” may provide viable and advantageous approaches to addressing several of the challenges facing the water supply community.

The paper attempts to provide a definition for “regional solution”, identify some of the key challenges facing water suppliers and describe how regional approaches may help aquifers meet their sustainability objectives:

1. Various options available for groundwater recharging.
2. Useful information, so that water agencies and other interested parties can better understand the pros and cons of the various alternatives available for their consideration.
3. Tools and lessons learned, so that the responsible authorities can chart a suitable course to regional agreements and cooperative arrangements.

Proposal:

Rainwater harvesting is a solution to water crisis**.** The proposal of the author in this paper is assembling a comprehensive picture of water harvesting topics ranging from technical to social and legal aspects:

1. The technology, design and utility of rainwater catchment's systems.
2. Consumer reactions to water conservation policy instruments.
3. Legislation and regulation demanding and influencing the efficient use of water harvesting.
4. Propose for establishing an organization entitles *National Water Harvesters' Network (NWHN)* which is a far-reaching network that addresses water issues through people from diverse background in abroad.

Conclusion

Water is nectar of life and life cannot sustain without it. Ever increasing demands of water for domestic, irrigation as well as industrial sectors have created water crisis worldwide. Ground water is the only dependable source of water. Inferior quality of groundwater with high salinity, fluoride and nitrate contents further limits the availability of fresh water assets.

Most of the traditional water harvesting systems have been neglected and fallen into disuse, but this is practiced on a large scale in countries like *Germany, Japan, United States*, and *Singapore*, where rainwater harvesting is a part of the state policy.

Depleting groundwater resources, water logging hazards, deep water levels, higher degree of salinity, high fluoride and nitrate concentration, industrial pollution etc. are the main ground water related areas of concern which needs appropriate attention of management for *Rain Water Harvesting & Artificial Recharging.* Rain water harvesting is essential because:

- Surface water is adequate to meet our demand and we have to depend on ground water.
- Due to rapid urbanization infiltration of rain water into the sub, soil has decreased drastically and recharging of ground water has diminished.
- Over- exploitation of ground water resources has resulted in declined in water levels in most part of the country.
- To enhance availability of ground water at specific place and time.
- To arrest sea water ingress.
- To improve the water quality in aquifers.
- To improve the vegetation cover.
- To raise the water levels in wells & bore wells that is drying up.
- To reduce power consumption.

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