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Achieving Ground Water Sustainability in Iran through Qanat Rejuvenation

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Abstract

Iran is the land of drought, floods and qanats. The ancient Persians discovered that the best place to store water was under ground, and the most appropriate method for its delivery was qanat. Their groundwater resources were sustainable before the importation of motor pumps and construction of large dams. The pumps enabled them to mine water from aquifers a few hundred meter deep and transporting it to mountain summits. The dam builders were either not aware of our geological and climatological settings, or ignored them. Enormous sedimentation, abundant evaporation, large leakage and astronomical costs make dams the most inappropriate technology for the Land of Iran and other dry lands of the world. Floodwater spreading for spate irrigation and the artificial recharge of groundwater (ARG) provides a low cost technology which is environmentally sound, financially viable and socially acceptable. The ARG on 14.9 million ha of our rain-fed farm fields and rangelands not only saves our groundwater for the future generations, but also rejuvenates about 30,000 desiccated qanats. Maintaining a rather constant flow in qanats is tantamount to groundwater sustainability. Our findings in Iran could be safely copied in other water-short regions of the world were wasted floodwater and suitable potential aquifers are available. We summarize results from a long-term ARG project and contrast them with detailed considerations of problems with the current practice of dams. Our results suggest that the rejuvenation of qanats is the better way to a sustainable water use in Iran.

Keywords: Artificial recharge of groundwater; Floodwater spreading; Gareh Bygone Plain; Iran; Qanat; Spate irrigation

Abbreviations: ARG: Artificial Recharge of Groundwater; AWC: Available Water Capacity; B:C: Benefit: Cost Ratio; FWS: Floodwater Spreading; GBP: Gareh Bygone Plain; MAP: Mean Annual Precipitation; MHA: Million Hectares.

Introduction

Water, the most precious commodity in deserts, is the single most natural resource that determines the suitability of a habitat for the living organisms. However, land and water are both sides of the same coin, as the food, fodder, feed, fiber and fuel wood produced directly by the green water have sustained the mankind, particularly the desert-dwellers, for untold generations. Moreover, supplemental irrigation has helped civilization establishment in dry lands. And where permanent streams are nonexistent, man had to resort to groundwater for staying alive. That is the paramount reason that although we are mostly concerned with the groundwater, we also discuss the land situation in the present day Iran, and relate it to the imminent demise of our groundwater resources, and the prudent management of the priceless potential aquifers in rejuvenating the qanats, the wonderful system that has sustained the Persians for millennia.

Qanat in a nutshell is a system that drains sloping aquifers and delivers the water to farms and population centers. It consists of a very mild-sloping gallery and numerous shafts for the pulling up the earth removed to form the gallery and for ventilation.

The History of Water Resources of Iran

While the mean annual precipitation (MAP) of the planet Earth is 860 mm, it is only about 240 mm in Iran, which comprises 1.1% of the continental areas. The MAP ranges from 2000 mm near the Talesh City in the north to less than 51 mm in the Central Desert. The rainy period in most of the country is from November to May. There is no rain in most of the country between May and October. About 90% of the total precipitation occurs in cold and humid seasons and in northern and western parts of the country, and only 10% occurs in warm and dry seasons and in central, southern and eastern parts. About 52% of precipitation occurs in 25% of the area of the country; hence, some parts of the land suffer from a lack of water resources, and imminent water crisis in the near future is a certainty [1].

Of the total of 415 km^3 of the MAP, 296 km^3 is counted as evapotranspiration; thus only 119 km^3 is readily available, of which about 94% is used to irrigate some 8 million hectares. Average volume of water input from rivers to the border is about 8 km^3 per year; on the debit side, 33 km^3 runs out of the country. Spring discharge is estimated at 10.7 km^3 per year. Surface water flow of rivers is about 99.7 km^3 and the annual infiltration into the aquifers estimated at 51 km^3 [1] Groundwater supplies about 60% of the national consumption in years with “normal” precipitation, and undoubtedly a larger percentage during prolonged drought, as the one we are experiencing now [2].

Occurrence of recurrent and prolonged droughts and torrential rains in many localities of Iran is a rule rather than exception; flash floods are the natural consequence of such events. This natural setting forced our pragmatic ancestors to invent the qanat, water resource management par excellence. Thus, Iran is the land of droughts, floods, and qanats.

Modernization zeal after the Second World War brought with it the disregard for our logical water management systems. It is ironic that how the higher education in the technically advanced countries could

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wreak havoc on the water resources of a so-called developing country! Qanat was the nemesis of the technocrats fresh out of illustrious American and European Universities. Large dams, with their energy-generating potentials were their first priority. Motor pumps, which could deliver water at the desired rate from depth down to hundreds of meters, and up the mountain summits was another answer to our water problems. Besides, the extremely photogenic large dams were the symbol of progress [3]. Evaporation from surface waters, annually ranging from 1.3 - 4.0 meters; this, for a reservoir close to Shiraz, amounts to 109 million m^3 per year. Extremely erodible watersheds and tectonic movements were easily neglected by the bureaucrats overwhelmed with the petrodollars.

Sedimentation behind large dams is a humanly unsolvable problem. The extremely large sediment deposition behind the existing dams, which is estimated at 200 million m^3 a year, the capacity of an average large dam in Iran, drastically decreases their useful life. The Sefeed-Rude Dam is a case in point. Of the 56,000 km^2 Sefeed-Rude Watershed, only 1,120 km^2 (2%) is covered with the Miocene and Plio-Pleistocene badlands. This small area, however, supplies 98% of the sediment in the reservoir of the Sefeed- Rude Dam. About 40% of the useful capacity of the reservoir was used up within 18 years; therefore, the useful life of the reservoir has been less than halved [4].

Plate tectonics: how the Red Sea opening endangers large dams in Iran

Subduction of the Afro-Arabian Plate under the Iranian Plate during the Upper Cretaceous, which continues to this day, has resulted in the formation of the Zagros Mountain Ranges and rising of the Iranian Plateau (Farhoudi, 1987) [5]. This rise that is about 17mm per year (Professor Farhoudi, personal communication) is mainly due to the opening of the Red Sea, and the 10-20-mm annual migration of the Arabian Homocline. The tremendous lateral pressure of the Afro-Arabian Plate to the several thousand meter thick carbonate deposits of the Zagros Mountain Ranges has formed well-developed karstic aquifers.

An abundance of solution channels in calcareous rocks, joints, crevices, cracks, and particularly faults in both the Zagros and Alborz Mountain Ranges makes these places very leaky. Leakage of the Lar Reservoir (north of Tehran) was estimated at 9-10 m^3 per second in 1985. Kowsar has observed one of the large solution channels with a flow rate of 16 m^3 per second, about half of the inflow of the reservoir, in June 1993. Leak-proofing this reservoir can be so expensive that it makes the project economically questionable [6]. Underground flow between adjacent watersheds is prevalent in Iran [7]. Active faulting and geothermal activities are important points that must be taken into consideration in siting a dam [6].

The majority of the 550 functioning large dams in Iran are located on potentially active faults (Professor Farhoudi, personal communication); this is also true for the proposed 500 other large dams, which are under the different stages of study. Thus, an untold number of Iranians are in danger of drowning and also the loss of the precious water in case of dam breakage. Figure 1 depicts the location of major faults in Iran. As marking the location of 1050 dam sites on the scale of this map is impractical, we present only the location of large dams in the Province of Fars. Table 2 presents the coordinates of the dams in that province. Figure 2 presents the major faults in the Province of Fars and the southern part of Iran.

Earthquake is another, ever present danger. In its slow but

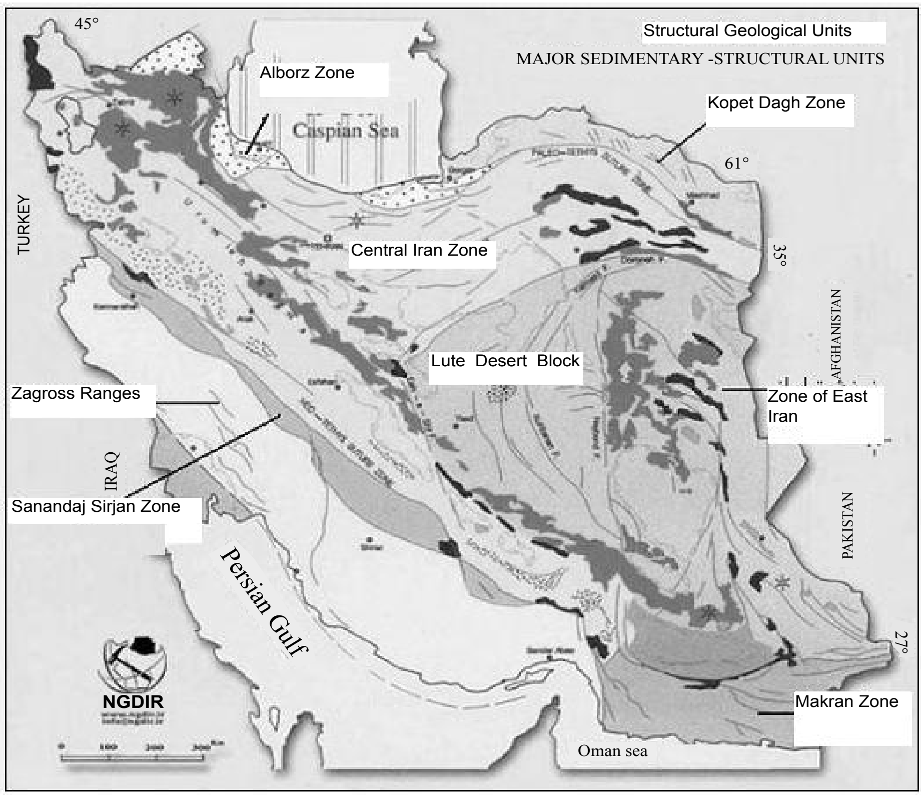

Figure 1: Units of the Iran's geological structures and the main faults (Source: Geological Survey of Iran).

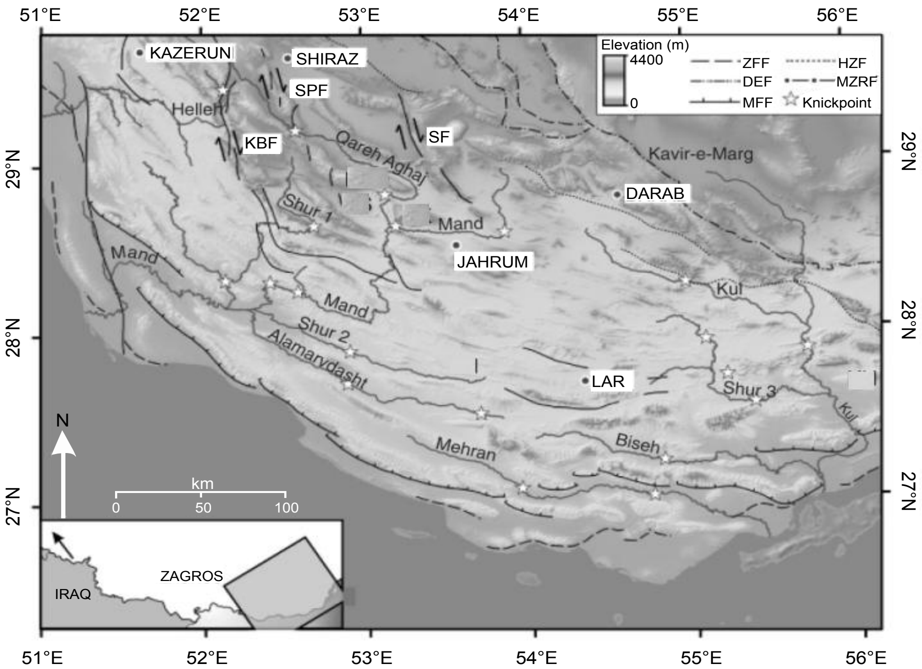

Figure 2: Fault map of the southern part of Iran:KBF= Karreh-Bas Fault, SPF=Sabzpooshan Fault, SF=Sarvestan Fault, ZFF: Zagros Foredeep Fault, DEF=Dezful Embayment Fault, MFF= Mountain Front Fault, HZF=High Zagros Fault, MZRF=Main Zagros Reverse Fault, Knickpoint= Abrupt changes in direction.

inexorable plunge under the Iranian Plate, the Afro-Arabian Plate may temporarily get stuck. If the sticking point gives way suddenly, the lurching ahead of the Afro-Arabian Plate produces an earthquake. As most of our large dams have been erected on fault, some of them active, their collapse in major earthquakes is a possibility that should not be ignored. Beside the naturally occurring tremors, the large dam-induced quakes should not be ignored. The Koynanagar earthquake of 11 Dec 1967 was reportedly induced by filling the reservoir of the Koyna Dam with 2780 million m^3 of water; this event claimed 180 human lives and injured 1500 people [8]. Gupta and Rastogi [9] have shown the significant relationships between dams and earthquakes. The Salman Farsi Dam in the Province of Fars has been erected on a fault that whose sudden jerk on 10 April 1972 caused numerous deaths! The intensity of that earthquake was 6.8 on the Richter scale. The dam was finished in 2007.

Tectonic uplifts and their effects on slope stability around the reservoirs is another undesirable outcome of the Red Sea opening on the dams built in the Zagros Mountain Ranges. Occurrence of huge landslides, and their accelerated plunge into reservoirs, causes a sudden rise in water surface and the resultant overflow of the dams and their probable collapse as it happened on 9 October 1963 to the Vaiont Dam in Italy. The deposition of 26 million m^3 of earth and rock in the reservoir in less than 10 seconds produced a 25 m tall wave that passed over the dam and ruined it [10].

The dams and pumps, in addition to three failed policies: nomad sedentarization, land reform, and self sufficiency in wheat and red meat resulted in the water mismanagement, particularly for the qanats which is the subject of this article.

As precipitation in the nomads' habitat was inadequate for a sedentary way of life, they learned that they had to obey the dictates of nature [11]. They had to make use of high mobility to adapt to the ever-changing dynamics of grasslands [12]. Moreover, their life in tents forced them to avoid exposure to extreme temperatures. Therefore, they moved between northerly summer camp sites and pastures at higher altitudes and lower, southerly sites in winter. By doing so, they utilized hundreds of thousands of square kilometers for grazing in order to maintain stock numbers in equilibrium with pasture productivity. Overgrazing was considered a sacrilege [13]. Thus, it is not surprising to find out that what Iranian nomads had learned through thousands of years of experience, only recently has been proven incontrovertible under similar environmental conditions.

Mobile pastoralism, which has been demonstrated by the Iranian nomads from time immemorial, is environmentally sustainable, financially sound, and socially acceptable in desert ecosystems [14,15]. In general, nomads are well-versed ecologists who shrewdly manage the environment; otherwise, they could not have lived that life for millennia. The nomads had learned to adapt themselves to the vagaries of climate by planning their itineraries and modifying the number of their livestock according to the forage availability.

It has been shown that the nomadic livestock systems are well adjusted to the ecosystems of the southern Sahel region [16], and even to the Himalayan environment; continuance of transhumance within the carrying capacity of the Niti valley (Nanda Devi Biosphere Reserve buffer zone) has been advised for effective management of available resources [17]. Moreover, Breman and de Wit (1983) have demonstrated that undeveloped, animal-based communities such as the southern Sahelian nomads are more energy efficient than modern, fuel-based societies.

Nomads spread their herds evenly across the landscape, thus causing less damage to the soil [18]. "Mobility is an ecological necessity, and the mobile pastoralism is often the best way to manage dry environments sustainably" (UNDP, 2003) [19]. On the contrary, concentration of humans and livestock into small areas degrades the soil, decreases the productive capacity of the land, and causes a decline in water resources and their quality. Sedentarization of nomad pastoralists has been an exercise in futility, and this has been concisely spelled out in a recent document by the United Nations [20]. Unfortunately, the decision-makers in dry lands are neither ecologist nor heed their consultation! *They cannot grasp the basic concepts of the carrying capacity.*

Political expediency lead the Government of Iran in the 1930s to decree that nomadism was an anachronism in the 20th century; those who practiced it must settle down, cultivate crops and raise domesticated animals. It was hard to rule the trekking people, scattered in far-away mountains and plains.

Iran was mostly an agrarian country to the middle of the 20th century using the traditional system of agronomy. The peasants of Iran constituted some three quarters of the country's population in the sixties [21], living in 48,592 villages [22]. Dry land agriculture provided a significant portion of staple crops of wheat and barley for both human and livestock consumption. Irrigation water was supplied through the springs, base flow of rivers and qanats, and using draught animals to extract water from shallow wells. Therefore, irrigation farmers planned their withdrawals commensurate with the flow rate of surface and qanat waters, and the number of beasts of burden they had at their disposal. Spate irrigation, a rudimentary method in which floodwater is diverted into the farm fields, was also practiced on a very large extent. Although there were numerous abysmally poor landless farmers who toiled as farm hands and share-croppers, the rest had a rather nominal income and were unknowingly the adherents of the green economy. Most landlords were paradoxically benevolent dictators, who, for their own benefit, managed the resources sustainably. Maintenance of the qanats was a timely and expensive routine that average farmers could not afford. If the landlord was short of cash for the dredging or rehabilitation of a qanat, he could borrow money on the strength of his landholding, a heavy burden that peasants were not able to shoulder.

The Land Reform Act of 1962-64 dealt the second serious blow to our natural resources. This law that had been promulgated to stem the spread of Communism did not achieve its objective as it was against the Islamic teachings, and the stakeholders were not allowed to participate in decision making. Article 64, Section B, Item 4 of the Compendium of the Land Reform Act specifies that each farming community will be allocated twice the area of its farm fields for livestock grazing. This enticed the powerful land owners to break the virgin land adjacent to their fields, thus claiming much larger extent than they had been previously farming. Unfortunately, in most instances these areas were ploughed with heavy machinery and used for cultivating crops. Furthermore, many landlords declined to maintain the qanats to show their resentment against the Government's decision, or could not afford it due to the decrease in their land holdings. Bonine (1996) [23] righly believes that the uncertainty about the ownership of qanats was a reason for the reduced community valuation of them. They resorted to wells with the catastrophic desiccation of the qanats.

The arrival of motor pumps drastically changed the picture. An extremely advantages characteristic of qanat, as far as transforming our fuel-based economy into a low-carbon, environmentally sustainable society, is that the water in this system flows by gravity, and no other source of energy is used to deliver water to the points of use, which have been originally selected to benefit from the qanat. This is in stark contrast to the tremendous amount of energy spent in pumping water from ever increasing depth of the over-exploited groundwater resources. Unfortunately, the loss of our most precious resource is accompanied by land subsidence in many plains, a deleterious occurrence that has been reported from other lands: Todd and Mays (2005) [24] have reported that more than 80 percent of the identified 17,000 square miles of land subsidence in the USA is due to over pumping of groundwater. Land subsidence in some areas of London had been 30 cm due to 150 years of water extraction from the Chalk (Wilson and Grace as reported by Bell, 1983) [25]. The coast of Osaka City had subsided about 3m, and the total area had settled 1m before 1992 due to the over-exploitation of groundwater since 1934 [26].

The national policies in the late 1970s starting to foster self-sufficiency in wheat and red meat further encouraged illegal expropriators to continue to overexploit the remaining land [13] and groundwater. Thus, the *coup de grâce* was dealt to our land and water resources. The establishment of 5^+ and 6^+ tons ha^{-1} wheat clubs in the 1990s wrongly persuaded farmers to over-fertilize and over-irrigate their fields in hope of receiving monetary rewards from the Government. The criterion was more yield per ha, and not the higher water use efficiency. Wheat production at any cost, resulted in severe over-exploitation of groundwater resources all over Iran, particularly in the Province of Fars, which is the breadbasket of this country. Supplementary irrigation of up to 14,000 m^3 ha^{-1} of wheat was common place. Thus, aquifer depletion is occurring despite the emphasis of Article33 of the Water Nationalization Act of September1968 that "*… holders of groundwater use permits are required to install measuring equipment on their wells and, upon request of the Ministry of Water and Power, to submit reports on the amount of water used*". Implementing this regulation would have prevented overdraft and salination of aquifers, and subsidence of their overlying land, which are rampant all over the Land of Iran. In the Kowsar's countrywide travels since 1968 he has never seen a single meter on a well. Now that we have reached the bottom of many aquifers, this regulation might be enforced. Disregard for regulations is rampant; e.g., the aquifers in the City of Jahrom, which is famous for its citrus fruits and dates, was decreed protected from new withdrawals in 1965. Negligence of this decree since 1979, encouraged by the heavily subsidized diesel fuel and electricity, has lowered the water table some 50 meters and desiccated many wells and qanats. Thus ignorance, greed, short-sightedness, and above all disregard for laws and regulations are depleting our groundwater by 6-8 km^3 a year.

The recent blanket issuance of permits for the illegally bored wells (upwards of 190,000, countrywide), decided by the majority vote in the House, is tantamount to rewarding the lawbreakers!

Although the water-related authorities in Iran are reluctant to admit the truth, we are facing initiation of a severe water crisis due to our mismanagement of water resources, particularly the groundwater. We present a concept that by raising the unconfined water table through the artificial recharge of groundwater (ARG) to the level of the desiccated qanats, so that they flow permanently, is a prudent method of water management that provides a logical alternative to building large dams to supply water to the deserts-dwellers. We back up our concept by presenting a 30-year case study, which proves that motor pump is a lethal device for the environmentally ignorant people.

Qanat: The Most Appropriate Technology for the Dry Lands of Iran

The geologic setting and the climatological conditions of the Land of Iran dictate that water should be stored underground. Karstic aquifers in the mountainous regions provide semi-permanent sources of very good quality water. However, most water in the plains and mountain valleys are obtained from qanats and wells. The vast alluvial deposits provide potential reservoirs for extremely large volume of water [27]. The ancient Persians transformed a man-made, uninhabitable desert into a garden through invention of the qanat [28]. The absolute requirement for a flowing qanat is the water table should be above the drainage line, at least at the invert of the mother well. Thus, maintaining the water table above a certain level is incontrovertible if an interruptible service is desired.

The qanat is *the* beacon of a sufficiently high water table; otherwise it would not flow. There are upward of 30,000 chains of desiccated qanats in Iran, a tremendous useless wealth if one considers the cost of digging a new one. Raising the water table through application of the ARG in the exceptionally wet years to above the invert of the mother wells initiates the flow. This indicates that the water table has reached a safe level. Therefore, wells sharing a common water table with a qanat should be operated in such a way that the mean flow of the qanat stays almost constant.

Floodwater Spreading Concepts

A. While the mean annual rainfall in dry lands is very low, its variability is very high (erratic in distribution and frequency). Thus, the chance of receiving the desired rainfall at the expected time is meager, indeed. Therefore, water is the most precious commodity and flood is its largest supplier in dry lands. Although floodwater is a renewable capital, its use must be optimized;

B. Available water capacity (AWC) is the most important direct driver of ecological sustainability in dry lands. Soil *texture* and *depth* are the two major determinants of AWC;

C. Water, an erosion agent, may become a land renovator and soil builder by transporting to and depositing nutritious sediment on the slightly-sloping, drastically disturbed lands, thus improving their texture and increasing their depth; *therefore, enhancing their AWC.*

D. High evaporation rate from surface waters, rapid siltation, inundation of historical monuments and productive lands and dwellings, forced migration of the inhabitants of the inundated area and construction sites, threat to biodiversity, reservoir leakage, earthquakes and other related environmental hazards, and the very high costs and relatively long time needed for their construction, make large dams the most *inappropriate technology* in dry lands. Furthermore, such schemes do not benefit inhabitants of the runoff-producing headwater catchments. They not only lose most of the water that Nature bestows upon them, but also the surface soil, the life-giving substance that nothing can replace; therefore,

E. Turbid floodwater should be harnessed to build soil and produce virtual water through spate irrigation, and/or it should be stored in aquifers by employing the artificial recharge of groundwater methods and used commensurate with needs. These shall also mitigate flooding hazards too [29].

The ARG may be defined as augmenting the natural movement of surface water into underground formations by some method of construction, by spreading water, or by artificially changing natural conditions (Todd and Mays, 2005) [24]. In our ARG systems, we divert a rather large flow, about 10 liters per second per ha, into 3-6 sedimentation basins. The rather clear water from these basins is drained into the recharge pond at the end of the system. The surcharge of this pond is returned into the river, or the next ARG system. The surface soil or sediments must attain field capacity before any drainage takes place. As the subsoil below the rooting zone stays close to field capacity, therefore, in the subsequent operations, most of the percolated water travels down to the shallow water table. As we have experienced a few deluges in the past 44 years, the potential to rejuvenate many of the desiccated qanats is understandable. Of course, it might take over a century to achieve our goal.

Floodwater Spreading: An Integrated Approach for Founding a Sustainable Green Economy

Runoff farming or spate irrigation of the staple crops and fodder has been practiced in dry lands from the ancient era. Evenari et al. (1971) [30] Shanan et al. (1970) [31], and Tadmor et al. (1970, 1971) [32,33] have extensively reported on the renovation of spate-irrigated farms planted with crops and trees in the Negev Desert. Mean grain barley yield on 650 ha of spate-irrigated fields in the Gareh Bygone Plain (GBP) was 1400 kg per ha while it was only 700 kg per ha on the adjacent rainfed farm fields [34]. It is important to note that dissolved and nutritious suspended load carried in floodwater greatly increase the productivity of spate-irrigated crops. We have observed that the soil organic matter and potassium [35] nitrate and ammonium [36] and mineral and organic phosphorus [37,38] concentrations have substantially improved in FWS systems. Therefore, floodwater spreading is the most environmentally sound and economically feasible method of reaching food and water security where the topography permits and the farm fields are underlain with potential shallow aquifers, as is the case in 14.9 million hectares (mha) of the arable land in Iran. Two to 4 fold increase in yield of spate-irrigated wheat and barley has been reported as compared to the rain-fed counterparts grown side by side [39]. Spate- irrigated improved rangelands have produced 4-30 fold of the untreated rangelands in southern Iran [40]; 17.3 mha of our rangelands are underlain with aquifers. Our reported 50,000 functioning and desiccated qanats are scattered beneath these farm fields and rangelands; therefore, spate irrigation of these expanses leads to the artificial recharge of our aquifers. It is estimated that the capacity of our alluvial aquifers is upwards of 5,000 km^3, 11 fold the Land of Iran's mean annual precipitation. This amounts to 40 years of our water use at the present extravagant consumption. Thus, raising the water table to the level of the "mother well" (the highest well that intercepts the water table), is a practicable technique that is environmentally sound and economically viable.

An important factor in considering the qanat system as opposed to other means of water collection and delivery is their presence in Iran and many other countries. Qanat construction, using the traditional method of digging by hand and hoisting the burrowed material by windlass, is very expensive. However, modern tools maybe employed to reduce costs and casualties. It is heartening to note that recently a qanat system has been proposed to annually supply 14 million m^3 of water for northern Cyprus, meeting the drinking water deficit of 13 million m^3 [41].

Another equally important advantage of spreading turbid floodwater on land is soil building. Land degradation worldwide annually takes 14-20 mha out of production (FAO, 1993) [42]. If this trend is continued unchecked, very little land remains to produce food on in less than 100 years! Deposition of the nutrient rich sediment on the degraded land restores its productivity. A case in point is the barley production of one ton per hectare on coarse-loamy sand after 2 years of spreading turbid floodwater on it, when the growing season precipitation was only 145 mm that induced 2 flooding events [39].

As the floodwater spreading is achieved by constructing level-silled channels, the banks formed by placing the burrowed earth upstream of the channels form a barrier against which the sediment settles down. Therefore, the sloping land eventually becomes level, thus its erodibility decreases substantially. Moreover, by providing forage in plains and on low-sloping rangelands the livestock may be kept out of the mountainous watersheds, helping nature to rehabilitate their degraded land, the water towers of the growing population.

Feasibility assessment of floodwater spreading systems for the artificial recharge of groundwater: A 30-year case study in the Gareh Bygone Plain

Hanjra and Gichuki [43] have presented evidence from Africa that adequate investment in land and water resources and related rural development activities leads to a higher level of agricultural productivity, which enhances economic growth for effective poverty alleviation. The main objective of this project was to stem the city ward migration of the nomad-turned irrigation farmers due to the desiccation of their qanats and wells, and to encourage them to return to their villages and produce sufficient income to stay there.

Gareh Bygone Plain (GBP), a part of the Sheebkuh Region, is located 50 km southeast of Fasa, between 53°50′ and 54°15′ longitudes and 28°30′ and 2845′ latitudes. Elevation of the GBP ranges from 1100 to1822 meters above the mean sea level. The mean annual precipitation (1971-2002) is 243.3mm, and the Class A pan evaporation is 3200 mm [44]. Of the 600-km^2 extent of the region, 150 km^2 is a rather flat plain and mountains cover the remainder. There are four relatively large ephemeral rivers named Gehrab, Bisheh Zard, Tchah Qootch and Bid Zard in this plain. It is estimated that the yearly flood volume is about 20 million m^3.

The floodwater spreading (FWS) project was initiated in 1983 utilizing the flow of the Bisheh Zard and Tchah Qootch rivers. Floodwater spreading systems were constructed on about 1365 ha of the sandy desert during the 1983-88 periods. Ahmad Abad, Rahim Abad, Bisheh Zard and Tchah Dowlat villages have received the most benefits from the project. The residents in these villages are mainly Arab nomads who were occupied by the traditional animal husbandry before initiation of the project, but their main occupation has changed to irrigated agriculture.

In a detailed study performed 11 years after the initiation of the project it was observed that irrigated area had reached 1193 ha, an 8 fold increase. This had provided a modest income for 250 owner-operators and 90 farm hands. Furthermore, the groundwater recharged by 4-5 ha of the recharge system was adequate for the supplemental irrigation of 5.5 ha, which supported a family of 7.4 persons, and provided employment opportunity for 0.38 persons. The benefit: cost (B: C) ratio in this study extrapolated to 20 years was 20 (Bakhtiar et al., 1997, Table 1) [45].

This is a very high ratio and few projects could be found with such a return.

The expansion of the FWS systems to 2033 ha after 2000 has provided more water for the irrigated farms and relatively abundant forage for the livestock. Provision of forage for the nomad-turned farmers' small livestock is vital for their well-being as well as the rehabilitation of our badly degraded rangelands. Results of an 18-year study in the GBP, the previous wintering ground of nomads, indicate that spate irrigation of a denuded rangeland increased its productivity both in wet (>200 mm MAP) and dry (<200 mm MAP) years. Mean dry matter yield were 519.29 and 166.90 kg ha^{-1} yr^{-1} for the spate-irrigated and control, respectively, in the wet years; this was 334.97 and 134.40 kg ha^{-1} yr^{-1} for the spate-irrigated and control, respectively, in the dry years; and 421.71(range: 136.0-721.5) and 149.69 (range: 78.0-350.2) kg ha^{-1} yr^{-1} for the spate-irrigated and control, respectively, during the 18-year period. Mean crown cover percentage for the mentioned treatments were 35.90 and 21.06 for the wet years; 30.27 and 17.59 for the dry years; and 32.92 (range: 19.00-67.09) and 19.22 (range: 9.70-30.20) during the same period. The higher yield ratio of spate-irrigated rangeland relative to control in droughts relative to wet years, 2.49 vs. 2.06, indicates the presence of a "pulse reserve" in the treated system [40].

Floodwater spreading for the artificial recharge of groundwater since January 1983 in 2033 ha of that plain has converted a substantial part of the degraded land into a livable place. The satellite imageries of 1984, 1998, and 2002 reveal that in addition to the flood irrigated systems, the area of poor and very poor rangeland has decreased by 827 ha. The mean annual increase in the yield of allowable use of forage due to spate irrigation has been 210.9 kg per ha. Assuming the nutritive

Year	Fixed costs	Variable costs	Total costs value	Costs present	Total income value	Income present
0	7226858	--	722685	27440380	--	--
1	6888666	1859233	8747899	30197747	2518534	8693979
2	8037421	3145463	1182884	350918901	74474868	233702136
3	4384388	4581610	8965998	25579992	97496952	278158804
4	4596115	5465096	10061211	6098781	156937479	407095820
5	7332875	76955732	1428860	3692535	238269907	561840441
6	--	8755681	8755681	18772180	276791644	593441285
7	--	10259990	10259990	19965940	350791573	683692776
8	--	11626253	11626253	206601720	315499737	559065534
9	--	13496549	13496549	21742940	468248319	754348042
10	--	15644674	15644674	22903803	585218666	856760127
11	--	20185880	20185880	26867406	1240345264	1650899546
12	--	25088531	25088531	30357122	1285978860	1556034421
13	--	38225958	38225958	42048554	973474920	1070822412
14-20	--	267581706	267581706	54961282	6950986417	1427732610
20	--	--	--	--	3153579450	1768226433
Total	--	--	--	622322272	--	12410514366

As it is shown in Table 1, the B/C ratio is: B/C=12,410,514,366/622,322,272=20

Table 1: The different costs and incomes and their present values at 10 percent discount rate, rials, 1983-2002 (after Bakhtiar et al., 1997) [45].

Name of the dams	Annual regulated water volume (MCM)*	Latitude (North)	Longitude (East)
Molla Sadra	329	30.6417	52.0819
Droud Zan	758	30.2056	52.4183
Sivand	92	30.1399	53.0839
Salman Farsi	313	28.5328	53.1203
Izadkhast	14.5	31.4817	52.1075
Firooz Abad	93	28.9472	52.5453

*Million m^3.
(Source: Ministry of Energy, Fars Regional Water Company).

Table 2: Large dams in the Province of Fars, their coordinates and potential water regulation.

value of the native forage is 0.8 that of alfalfa, and the daily intake of an average weight livestock (30.0 kg) is 1.5 kg, the 1728 ha that receive good watering can annually support 677 heads of livestock. Moreover, the stubble produced in an additional 700 ha of irrigated fields supply stubble for an extra 1917 heads of sheep and goats in the droughty years. This, and the extra income from the irrigated agriculture, has placed most of the mixed farmers above the poverty line.

A better indicator for the effectiveness of spate-irrigation of a rangeland is an increase in the kilogram of meat, fleece and hair produced per ha relative to the control. However, the secretiveness of the settled nomads, which has been ingrained in them through the centuries of evading heavy-handed tax collectors and marauding bandits, deprived us of obtaining accurate data on the jump in their income due to the accomplished activities. Therefore, we have to rely on anecdotal evidence and rumors: unheard of double-kidding and lambing occurred in the 1984-85 breeding season and thereafter; purchasing and renewing cars and pickup trucks has become a yearly ritual for the formerly disadvantaged herders; a nearly 1000-fold increase in the price of farm lands, etc. [40].

Environmental Benefits

Floodwater spreading has transformed a sandy expanse into a verdant scenery. The 90 ha afforested area and 30 km of wind breaks have ameliorated the harsh conditions of a desert. Day time temperature in summer is 4˚C lower, and the night time temperature in winter is 4˚C higher than the surrounding desert. This decreases the required energy for the cooling and warming of the residential areas [46].The moving sand has been fixed by the sediment and the wildlife has found a nice refuge among the trees. The ARG systems have become a camping ground for the local as well as the tourists who frequent the area in the spring.

The beekeeping industry's financial gain from the organically produced honey is substantial; the average annual honey production of the *Eucalyptus camaldulensis* Dehnh. Trees are 35 metric tons; however, the potential seems to be higher [47]. It is refreshing to note that we have recently received the organic seal for the honey produced in the GBP. The price has jumped 3 fold for the honey. The trees, bushes, grasses and forbs also sequester carbon; the above ground carbon sequestration potential of an 18-year old, spate-irrigated *Eucalyptus camaldulensis* Dehnh. Trees was 2.221 metric tons ha^{-1} year^{-1} this for *Acacia salicina* Lindl. Was 1.304 metric tons ha^{-1} year^{-1} [44,48]. Should the industrial nations pay the carbon rent, the annually sequestered upwards of 400 metric tons can bring an extra income to the residents of the plain.

An improvement in water quantity and quality has encouraged many migrants to return home and become producers, not consumers. The electrical conductivity of groundwater in the well that supplied domestic water to Rahim Abad has decreased 3.29 fold [49]. The nitrate content of the floodwater that recharges the aquifer is 60 mg per liter; however, that of the recharged water downstream of the eucalyptus forests is 7.1 mg per liter [2].

Although pricing of the intangible benefits is subjective, as nobody may put a price for a flood-drowned person (about 200 a year in Iran) or beautification of scenery, it has been attempted by Karimzadegan et al. [50]. They have found that the B: C ratio of the afforestation in the GBP for climate amelioration, soil conservation, and wildlife refuge establishment amounts to70: l.

Conclusions

Spate irrigation of scrubland, rangeland, and cropland on 14.9 million ha of potential aquifers will hopefully rejuvenate some 30,000 desiccated qanats and retire hundreds of thousands of pumping station, thus a very large amount of energy will be saved, and a low-carbon economy will result. The artificial recharge of groundwater offers a sustainable technology for water resources development and use in dry lands. Enormous sedimentation and evaporation rates, extremely large leakage and astronomical costs make large dams inappropriate structures for the desert environments. Qanats are the most appropriate means of groundwater collection and delivery system. We will be running out of suitable site for dam construction in less than 150 years if the current erosion rate is maintained. Therefore, the sooner we realize the merits of qanats, the better. Provision of employment opportunities for approximately 4 million persons in a green economy is a windfall of the materialization of this concept. Therefore, considering the information summarized in this paper, dams do not seem to be as appropriate as qanats.

Although this proposal may seem "*utopian*" to our water policy-makers bent on building more large dams, there is no other way to save our groundwater. That is the main reason that we have planned an *Aquitopia* with the help of the UNU/INWEH, UNESCO-MAB Programme, and the Flemish Government of Belgium. We have appropriated some 1200 ha of a depleted rangeland underlain by a potential aquifer with an estimated capacity of 50 million m^3. This is the site of a utopia based on aquifer management. Forty young couples and 30 research scientists and technicians plant 440 ha of irrigated crops and 550 ha of fodder and 55 ha of trees (fruits and trees visited by honeybees) with spate-irrigation. Each utopian can raise 10 heads of sheep and goats. The utopians will live in a green village. Wind and sun, plus fuel wood provide the needed energy. Desert architecture shall be adhered to; e.g. wind towers provide the cooling system, and shelterbelts modify the extremes of temperature. The foundation philosophy is respect for the Nature. We have already constructed some 300 ha of the spate-irrigated systems there. They function as the ARG system, as the water not consumed by the plants, eventually raises the water table.

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