UNESCO G-WADI MEETING ON WATER HARVESTING
ALEPPO SYRIA
20-22nd NOVEMBER 2006

FINAL REPORT

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Prof W M Edmunds and C Cardona (editors)

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1 Meeting Background - The UNESCO G-Wadi Network

The strategic objective of the G-WADI Network is to strengthen the global capacity to manage the water resources of arid and semi-arid areas. Its primary aim is to build an effective global community through integration of selected existing material from networks, centres, organizations and individuals. The Network promotes international and regional cooperation in these areas.

Interest was expressed at the Second Global meeting of G-WADI in Paris 2005 that Water Harvesting should become a new web-based initiative for 2006. This would encompass both rainwater harvesting (RWH) and managed aquifer recharge (MAR). The collection and storage of rainwater has been a traditional activity in the Indian Subcontinent as well as in countries of the Middle East and North Africa for more than two millennia. Water harvesting is also now a growing practice especially in many semi-arid zones and has a strong tradition especially in West Asia and Middle East. Water harvesting is a key activity in helping poorer communities in rural areas to find water security, thereby promoting sustainable livelihoods. However water harvesting at many scales is also taking place in urban and rural environments.

1.1 OBJECTIVES

The purpose of the Aleppo workshop was to develop a G-WADI programme on Water Harvesting and with the following objectives:

1. Linking the UNESCO G-WADI activity with those of other International Organizations active in the same field, including the IAH (International Association of Hydrogeologists), IWHA (International Water History Association) ICQHS (International Centre on Qanats and Historic Hydraulic Structures) and others in the region including ICARDA and ACSAD (Arab Centre for Semi Arid Zones and Drylands
2. To compare the practice of RWH across the regions of the "Old World" as a basis for inter-comparison with other global semi-arid regions
3. Summary of the state of the art through a series of invited talks and discussion
4. Develop a programme of case studies from invited contributions and best practice from all regions, especially studies which have proper validation
5. Consider ways in which the web site may be used to disseminate and discuss design criteria for water harvesting, raising awareness and link to traditional technologies where water harvesting is well known
6. Consider use of a systems approach to link small-scale activities in rainwater harvesting, surface water storage and MAR. The opportunity also exists to apply satellite based tools (HYDIS for example) to consider rainfall patterns and drought index.
7. To generate links and interest with institutions, NGOs working in the field of RWH and MAR in the Asia–Middle-East–Mediterranean region as basis for extension and dissemination worldwide.

1.2 LOCAL ARRANGEMENTS AND SCIENTIFIC REQUIREMENTS

The meeting was coordinated by Oxford University with the local arrangements and programme being organized by ICARDA. The meeting was held at ICARDA Headquarters (some 30km from Aleppo). The programme is included as Appendix 1 and the full list of participants as Appendix 4.

Since the purpose of the workshop was to create a web activity on the subject of RWH, participants were invited to submit titles and short abstracts of their presentations in advance of the meeting. Oral presentations were invited as Powerpoint slides and 4-page written papers were also contributed. Participants were also invited to bring along any printed materials on water harvesting, particularly items meant to provide guidance, along good pictures, diagrams, video, maps that might be useful in developing the web site.

2 Main conference report

2.1 OPENING REMARKS

Dr. Theib Oweis and Dr Mahmoud Solh (ICARDA), Dr Abdin Salih (UNSECO) and Prof. Mike Edmunds (G-WADI) highlighted the significance of the UNESCO G-WADI meeting on rainwater harvesting in particular to semi-arid and arid dry lands such as those presented by the participants during the seminar. It was pointed out that the very existence of the UNESCO G-WADI established network revealed that water resources are no longer seen to be a mere commodity but a scarce resource that requires careful management. Rainwater harvesting in particular was seen to be key in dry areas since its immediate implications are to increase yields and improve the livelihoods of dry area farmers.

The importance of the technology of the Qanat was also stressed. The restructuring and enhancement of qanat technologies in the Middle East and India in particular, sends one clear message that there is a reinvention of the wheel and a rediscovery of ancient RWH technologies. In this way it was recognised that indigenous knowledge is precious and should be integrated harmoniously with modern technologies.

Finally the dominance of climate change, its consequence of placing countries into jeopardy due to less reliable water supplies and increased uncertainties has meant that rainwater harvesting should all the more be studied and adopted as a valuable augmentation or alternative to conventional water supply sources

In light of the above the UNESCO-G-WADI meeting aimed at capturing the importance of RWH systems as was pioneered in the old times and simultaneously allowing the dissemination of information so that the Old and New Worlds could learn from oneanother.

2.2 MAIN INTERNATIONAL PROGRAMMES

UNESCO

The International Hydrological Programme is a UNESCO initiative that started at the beginning of the water decade. It concentrated initially on Research and Development but gradually moved on to its 6th Phase which meant the identification of most crucial water related areas and identification of major pressures that threaten waters quality and quantity status.

Several groundwater initiatives were evoked such as MAR, HELP, FRIEND and WWAP, PPCP/WAP and also the highly regarded World Water Assessment Programme on the State of World's Freshwater Resources. Such projects have now spread across the world, and in so doing tip the balance in favour of cooperation and simultaneously away from potential conflict to enhance water security. IHP 7 (2008-2013) will be looking at 4 approved themes which are:

(i) Global changes

(ii) Governance

(iii) Ecohydrology

(iv) Water quality

G_WADI

Following UNESCO's achievements the main GWADI activities were presented. These include several from information system networking by means of its website (http://www.gwadi.org/), workshop initiatives such as the Isotopic and Chemical Tracers in Hydrology to facilitate the application of chemical tools and state-of-the art isotopic tracers in semi-arid and arid areas; international modelling workshops such as the last one held in Roorkee in early 2005 to provide modelling support and access to appropriate software tools as well as provide web-based training materials. In addition to this there is also the WMO-GWADI initiative to apply climatic research as well as the setting up of the steering committee. Plans for the future include amongst others the translation of the website into several languages.

By means of these several initiatives UNESCO has facilitated the setting up a network between diverse organisations. The valuable training role of the UNESCO-IHE Education Institute for water research at Delft was also acknowledged.

IAH-MAR

The IAH-MAR programme (www.iah.org/recharge) exists to facilitate exchange, research dissemination and to promote joint projects between hydrogeologists and others. Ian Gale presented an overview of recent activities and how IAH-MAR was interested in linkage with the G-WADI programme. The related IGRAC programme (International Groundwater Resources Assessment Centre (www.igrac.nl) contains some activities that are relevant including - dissemination of groundwater information to non-english speakers, arid cities security, governance in MAR, clogging of recharge structures and cost benefit analysis of MAR.

ACSAD

Dr. Abdullah Droubi gave an overview of the activities of ACSAD, Arab Centre for Semi-Arid Zones and Drylands, based in Damascus (www.acsad.org). ACSAD is a specialized Arab organization working within the framework of the League of Arab States with the objective of unifying the Arab efforts which aim to develop the scientific agricultural research in the arid and semi-arid areas, help in the exchange of information and experiences and make use of the scientific progress and the modern agricultural techniques in order to increase the agricultural production. Only 10% of water is renewed through recharge in arid lands. ACSAD programmes focus on aridity, droughts and shared water. More than 80% (87.3%) of water is withdrawn by the agricultural sector in all Arab countries. By 2025 a severe water deficit and a mere 40% food sufficiency is being projected.

ICQHS

Dr Semsar Yazdi, outlined the programme of the International Centre for Qanats and Historic Hydraulic Structures and conveyed best wishes of Dr Zargar, Iranian Deputy Minister of Energy for Water Affairs and Chairman of ICQHS; Dr Zargar had reluctantly to cancel his visit at short notice. The Centre, based in Yazd, was formally opened in 2005 with the support of UNESCO (www.qanat.info). Its main role is to preserve the engineering, cultural and social information on qanats and related structures, transfer of knowledge and to promote research and development, to sustain and to restore qanats and related structures, which have proved to provide sustainable resources for over two millennia

ICARDA

The programme of ICARDA, hosts for the meeting, is directly relevant to water harvesting activities. Dr Thieb Oweis gave an overview of relevant aspects of the programme. ICARDA (www.icarda.cgiar.org) is one of 16 Centres supported by CGIAR which serve developing countries in improving agriculture, improvement of on-farm water-use efficiency for example. These activities have a direct impact on poverty alleviation through productivity improvements integrated with sustainable natural-resource management practices. ICARDA meets these challenges through research, training and dissemination of information through different levels of cooperation. ICARDA produces some excellent publications and handbooks related to water harvesting including traditional uses and water use efficiency in agriculture.

2.3 SESSION 1: HISTORICAL AND TRADITIONAL PERSPECTIVES

Dr. Samsar Yazdi Director UNESCO ICQHS Yazd gave a fascinating presentation on the endeavours carried out in accordance with qanat technology and historic hydraulic structures in Iran. The vital role qanats played as a stimulus for human societies whose survival was dependant on these systems was portrayed by examples given from Iran, Oman and Afghanisitan. A total of 34355 qanats were identified in Iran and are reputed to give a total discharge of 8,212 billion m^3.

He outlined how qanats had fared through the history of Persia from their founding in 714BC, with periods of decline, abandonment and reinstatement. The qanats are recognised invaluable historical legacies and yet it has been questioned how such qanats can be reinvigorated or rehabilitated. Major difficulties in their rehabilitation in Iran are due to the overexploitation and falling down of the water table. Therefore out of 609 basins a mere 220 have been defined as restricted areas. under water exploitation supervision and where the blockage of unauthorised wells actually takes place.

In May 2000 city of Yazd situated in centre of Iran hosted an International conference on Qanat under the auspices of UNESCO. At this conference the idea of the establishment of an International Centre on Qanat was put forward and was stipulated at another conference on Qanat held in 2002 in Oman. The IR of Iran's proposal concerning the establishment of the International Centre on Qanat met with UNESCO's approval in 2003. in March 2005 the agreement of the establishment and operation of the centre was signed between IR of Iran and UNESCO. The purpose of the centre is to maintain and restore such historical structures as well as the transfer of know how, experiences and traditional knowledge related to Qanat.

In the future the ICQHS plans to determine the budget required and finalise joint research projects with various centres. The transmission of knowledge has always been a priority of this organisation and thus the erection of a data bank is deemed to be essential. The compilation of the first history of Qanats is one step further in the direction of knowledge dissemination.

Conclusions from discussions

The discussion that emerged after this presentation rotated around the question of how societies can relate to the qanat system for rainwater harvesting. It was noted that today several artificial dams have been constructed upstream of qanats, This has aided the discharge of qanats and is a clear example of modern soft engineering technologies involving rainwater harvesting enhancing qanat technology.

Ms. Gita Kavarana (CSE Delhi India) further exposed the significance of traditional rainwater harvesting systems through her portrayal of a rich multitude of rainwater harvesting technologies and practices in the semi-arid and arid regions of Rajasthan and Gujarat. One of the most essential points stressed by Ms. Kavarana was the actual involvement of the public. She highlighted this by presenting an excellent video clip of a nationwide TV advertisement that was created to reenact and popularize ‘the importance of a raindrop’ amongst Indians.

India spent around US $ 650 billion on water supply projects during the past few years but this was to no avail. The solution has been recognized to lie in the utilization of traditional systems which make sense in the Indian sub-continent particularly due to the monsoonal concentration of rainfall in India. An interesting point made was that if one was to take a mere 3% of land in India and construct 30,000 tankas, a total of $9Mm^3$ of water can be harvested. It was reported that this is what all surface and groundwater resources are currently contributing in India.

Again the bottom-up role of the local people was stressed since ultimately they are the ones that manage these traditional forms of rainwater harvesting and the problems of bureaucracy in their management do not seep in.

A substantial number of diverse traditional RWH technologies coming from the Indian sub-continent were mentioned and explained. A short list of some of these included diversion channels, rain-fed storage structures, bamboo systems, qanats (practiced by the Mogul Kings in Uttar Pradesh), *surangam*, tanks or *sagar*, *bandhas*, *chaukas* or *tobas* and *rapats* All of these and much more were strikingly presented on a map of India revealing the rich diversity and dispersion of tradition across the country.

Unique rainwater harvesting systems which emerged from the several examples given included constructed underground rainwater harvesting systems in floodplain regions so as to reduce evaporation; in coastal areas the fresh water-salt water interface was used as a technique to harvest rainwater (known as *Virda*); and the glacial melt stored in mountainous regions was transferred to fields. Case study examples given included the Town of Dholavira of the Indus Valley where inhabitants tapped water from 2 channels that were constructed adjacent to the 2 sides of the city. In the Thar Desert local reservoirs called *talab* were made out of natural depressions and in urban areas roof water harvesting systems were used together with *tankas* that were constructed in courtyards. Temple sites made use of step wells (*chadras*), some of which went down to a depth of 2m. As for agricultural practices, embankments or *khadin* were built across slopes so that rainwater could gradually collect in fields which lay at the foot of slopes.

Social discipline emerged as a significant factor in the management of these structures. This was portrayed through the example given of people not being allowed to walk in the catchment designated for a certain RWH structure in order to maintain good water quality. Also an effort to clean the catchment prior to the monsoonal rains was considered a must. One must not exclude the role of knowledge. Traditional harvesting of rain could not have been possible without perceptive knowledge on the physical characteristics such as the geology of the area.

Ms. Kavarana claimed that the decline in the appropriate use of such systems came about due to the shift in the public's mentality of water being a *right* and not a *responsibility*. Water was not considered a free good in the past. Fines existed for the violation of irrigation rules, for instance. Once a bureaucracy was introduced in India during British rule, community ownership of such systems was lost.

Conclusions from discussion

Therefore in conclusion to the Indian experience, the main lesson learnt was that rainwater harvesting is a tool for social mobilization since it empowers people and enables proper governance of water resources. Ms. Kavarana ended by linking this lesson to what CSE is doing today. CSE believes in public involvement and raising awareness. Water harvesting manuals have been created and dispersed, whilst workshops and advisory centres have also been set up.

Bridging traditional RWH techniques with the present

Dr Theib Oweis innovatively linked the past two presentations that focused on traditional and historic perspectives with the present day. Bridging the gap between traditional and modern water technologies is a challenge since people often confuse techniques with indigenous knowledge. There is a growing perception that older techniques are far better than modern techniques.

This point was illustrated by the ceramic pot technology for small scale irrigation, which was a success a long time ago however one has to question whether it is still suitable today and whether there is a better technology now.

Indigenous knowledge has been useful in creating modern techniques. For instance drip irrigation technology, a relatively modern concept, came into being a long time ago through the ceramic pot technique. In the Negev desert a concave rock was used to condense water and collect the condensed water in hollows or basins that were placed beneath the rock. Today this ancient technique has led to drip irrigation since materials are cheaper and more affordable.

However a case in point where indigenous knowledge has not been applied appropriately is for instance in submerged land levelling, a technique that was essential to improve rice production. In Egypt oxen were used for levelling and today expensive and often unaffordable machinery is used. Another example given was that of head or energy required to get water from the aquifer. To do so qanat technology evolved. Modern achievement of head is through pumping which has led to abuse and over abstraction.

The examples Dr. Oweis illustrated revealed that it cannot be assumed that indigenous techniques are ideal for all times. It is Indigenous Knowledge combined with advanced science that ensures efficient application of modern technologies today. To indicate that this is possible Dr. Oweis highlighted the improvement of traditional agricultural RWH technologies by making the catchment more effective in transferring water. Contour bench terraces in Tunisia and Yemen, wadi bed stone walls, contour ridges and laser-guided contour bunds, as well as semi-circular bunds in Tabia, Tunisia all reveal that manual and mechanical construction and techniques have been integrated.

Conclusions from discussions

It was concluded that indigenous knowledge can be applied to modern ways through research and thus there is an urgent need for documenting and communicating this knowledge. The importance of understanding the environmental costs that are induced by such technologies is also crucial. Traditional rainwater harvesting techniques cannot be blindly applied to any circumstance or situation. An impact assessment of their implementation has to be carried out prior to them being adopted

2.4 SESSION 2: ENVIRONMENTAL AND SOCIETAL CONTEXT.

The environmental and societal context of rainwater harvesting was well illustrated by means of 4 presentations covering the Indian subcontinent, the Middle East and the Mediterranean semi-arid region. This session was essential since it exposed the significant role the public plays in first accepting and then integrating rainwater harvesting and managed aquifer recharge techniques within their environments. The session also revealed how crucial it is to understand the natural environment in its holistic way in order to fully exploit the total potential of RWH and MAR techniques and apply them in the most appropriate or ideal locations, adversely impacting the environment in the least way possible.

The water harvesting context in the Indian subcontinent was once again presented by Dr. Anupma Sharma. An overview of the role of societies in the successful implementation of RWH schemes in India, Sri Lanka, Bangladesh and Nepal were given. With the amount of rainfall in the Indian sub continent one would be mistaken that there are no water deficiencies. However the great difference in rainfall variability dictates otherwise. In 1947 the availability of water per capita stood at 6000m^3, and in 2006 at 2000m^3. These figures are still above the poverty line however the maximum amount of precipitation is only received in a minimal amount of hours. 70% of surface waters and a large proportion of groundwaters are known to be polluted.

Thus the freshwater crisis in this subcontinent has been inflicted by means of the rampant pollution of freshwater resources, inadequate attention, very low prices, uncontrolled boreholes and communities whose work is fragmented. Dug wells are reported to have increased in number from 3 to 9 million and sea water intrusion in coastal areas has become rampant. Rainwater harvesting is thus seen as an alternative source. Around 1-2% of India's land captures rain providing a total of 950 million people 10 l a day with water!

Several watershed development programmes have been set up to enhance rainwater harvesting practices. Many of these campaigns have an underlying waterwatch motto and enable the rural population, executed by the village governing bodies, to actively participate in the introduction and upkeep of RWH schemes. The role of women is also significant in these campaigns and is encouraged. This often causes a positive snowball effect in small communities as more and more females are encouraged to take an active part in RWH implementation. As a result of these campaigns, water harvesting structures of capacity up to 18000M m3 of water were constructed by the Indian Government in Uttar Pradesh, 2003.

The Bangladesh case presented by Dr. Anupma revealed the benefits harvested rainwater can provide when it comes to providing alternative water to contaminated water supplies. Arsenic contamination is severe in the western and south western parts of Bangladesh. But most buildings are not designed for rainwater harvesting in these areas. Tin roofed houses require modifications through the utilisation of gutters.

In the case of Nepal 67% of the population have access to safe drinking water. Fog water collection is practiced but more importantly was the mention of indiscriminate rainwater harvesting from upstream users. It was pointed out by Dr. Anupma that upstream users have to care for downstream users when harvesting rainwater and therefore there is always a need for research in order to be able to anticipate the impacts by upstream RWH on downstream users.

Further social benefits of RWH were exposed through Dr. Droubi's succeeding presentation on the use of RWH to alleviate poverty in rural areas. He related the ACSAD experience in the Arab Region. The trend in several Arab countries has been prolonged drought such as that of Cyprus (1991) and Jordan (1998/1999). Dr. Droubi clearly depicted the situation in Syria where average rainfall is about 1000mm in the mountainous areas during the winter months. Summer scarcity means that water is bought expensively. The wadis and terraces in the watershed are used to cultivate wheat. Outcrops of fissured limestone permit rapid recharge.

However poverty is a main characteristic of the area; the elderly are abandoned to make their own living whilst the economically active leave to find work in the city. ACSAD enabled the introduction of a new variety of wheat together with new crops including medicinal plants and fruit trees. Supplementary water sources were also seen to be vital prerequisites to curtail poverty in the area.

Thus modelling for the location of artificial lakes or dams was carried out and a hill reservoir using 1000 micron LDPE sheets for lining was constructed. The end result was a storage lake with a capacity of 7000m^3. After creating the lake, water was pumped through 100m polystyrene pipes and tobacco was grown. A picture shown by Dr. Droubi revealed the significant difference between the rainfed and irrigated tobacco grown in the same field. Irrigation doubled the income and the introduced ACSAD varieties improved the local varieties.

Similar projects and outcomes resulted in Shihah, Syria and the Al-Ramaa area in Yemen. Pilot projects were attempted in 4 Arab countries in order to understand and simulate a model on water flow.

RWH in semi-arid Island environments

Issues relating to RWH in semi-arid islands followed and was presented by Ms Cardona from the Malta Resources Authority. Her talk explored the potential of small-scale domestic rainwater harvesting on the island of Malta by taking an integrated look at the physical, social, and economic environments. The extent to which domestic rainwater harvesting has been forgotten despite the fact of it being embedded within Malta's history for centuries was emphasised The case study, based on residential and water professional interviews, examined the cost-effectiveness of RWH technology both at a local and the national scale and teases out the hurdles that have brought about its rejection residential and water professional interviews.

67% of original RWH structures are still used for agricultural and other purposes. From the study it was evident that island characteristics of smallness, contested land and limited space; lack of proper planning and enforcement have instigated the decline in the use of rainwater cisterns. Also a low shadow pricing of water, despite public perception that government water tariffs are high; and a high financial cost of cistern construction have further limited the potential of its widespread application. Increasing reliance on reverse osmosis desalination for water supply often makes RWH the less attractive option. Moreover small scale rainwater harvesting does not at present attract the required attention in order for it to be encouraged nationally.

In conclusion proper planning, enforcement, education and regulation, as well as policy integration seem to be key to unlocking the reluctance of RWH use.

Defining sustainable yields for rainwater harvesting

Prof. Howard Wheater closed this session by presenting his experiences relating to the definition of sustainable yields for rainwater harvesting. Prof. Wheater stressed at the start of his presentation that thinking about RWH leads to the setting up of methods for harvesting the rain which in turn lead to sustainable issues since a sustainable yield has to be predetermined from the start. Professor Wheater drew the participants' attention to the need to consider the sustainable yield of rainwater harvesting systems and not just the methods of rainwater collection. In semi-arid and arid areas rainfall collection is not so straightforward because of its extreme variability. Therefore taking mean annual rainfall as an indicator to test the potential of rainwater harvesting in an area is far from being accurate. The intermittancy and interannual variability in rainfall needs to be taken into account.

In arid areas, high evaporation rates means that managed aquifer recharge is the most attractive option for increasing water availability. An example of the investment in recharge dams on the Batinah coastal plain of Northern Oman was given to illustrate this point. Such dams with restricted discharge outlets are able to retain water behind the structure and slow the downstream transmission of stormwater. In this way groundwater recharge is focussed behind and immediately downstream of the dam. In coastal environments the location of these dams can enhance recharge which in turn will combat the problems of saline intrusion in coastal aquifers.

The sustainable yield of these systems must be assessed and this is a complex task due to the spatial variability that exists within surface and groundwater interactions. This is why, as Professor Wheater highlights, there is a need for comprehensive monitoring network of surface and groundwater interactions. Equally important is the consideration of groundwater quality considerations. The few holistic studies that exist are often unavailable to the public sphere since they are unpublished works.

The definition of sustainable yields for managed groundwater recharge was portrayed through the case of a study carried out on a proposed recharge dam in a wadi system in Northern Oman whereby a modelling framework was developed to capture the spatial variability of rainfall, runoff generation and groundwater recharge. A stochastic rainfall generator was developed empirically form the available raingauge network. A specially designed rainfall-runoff model was created to generate the spatial distribution of runoff and flow routing in the wadi channel network. Transmission losses were also taken into account. This model could then be combined with groundwater model to see the groundwater response.

Such a study was deemed important because within the distributed rainfall-runoff model it was possible to explore the response to recharge dams of different sizes and locations, for a number of years of stochastically-generated daily spatial rainfall inputs. In that way the potential yields of alternative designs could be evaluated in a risk-based framework.

Modelling similar to this study is in its embryonic stage, has received little attention and needs to be developed further. Prof Wheater added that such modelling systems could also be linked with Global Climate Model scenarios of future climate, and hence evaluate the response to climate change.

A final important point was related to water quality. Enhanced recharge can improve groundwater quality. On the other hand rising water tables could mobilise naturally anthropogenically-generated pollution. Land use patterns and management effects on rainwater quality would also be needed to be incorporated within the modelling framework. When taken in their total potential these models can provide an extremely effective means of informing policy makers and simultaneously address the concept of integrated water resource management.

2.5 SESSION 3: CASE STUDIES AND MODERN PRACTICE

Managed Aquifer Recharge

Mr Ian Gale from the British Geological Survey gave a realistic view of managed aquifer recharge stressing that often MAR is simply seen as a panacea for water supply problems worldwide and that not enough attention is given to the actual evaluation of the effectiveness of such structures. Thus, it was highlighted that MAR should be evaluated in its totality by considering its potential in different climatic, hydrogeological and socio-economic conditions.

This important evaluation of the impacts of MAR structures was depicted using 3 cases whereby 3 research sites in India, were established and monitored. These were Satlasana, Gujarat; the Kolwan Valley, in the Maharashtra state and Kodangipalayam in Tamil Nadu. All 3 sites were representative of different hydrological and socio-environmental characteristics and thus two studies; a physical and socio-economic one were carried out to obtain further understanding of each sites uniqueness. Baseline surveys included geological mapping; the identification of hydrogeologically important features and topographical surveys. Several components such as rainfall, evaporation rates, groundwater levels and surface flows, climate, and sediment flow had to be monitored. In addition to this water samples had to be systematically collected to determine the quality of the water in the local wells in order to assess any possible change in water quality brought about by the MAR structures.

Attention was brought to the fact that the findings of the 3 sites are only preliminary since inter-annnual and annual variability in climate dictates that monitoring over a long-term period is required to obtain a more precise picture. From these initial findings, however, it was brought to the fore, that the effectiveness of each recharge structure in the states was dependent upon rainfall, geology and the actual usage of water abstracted. In the Gujurat case, for instance, actual spilling of the check dam resulted due to the sudden and short duration of the torrential storm. Because of the coarse nature of the sediments in the headwaters of the catchment, rapid infiltration of water to replenish the aquifer resulted. Also, the stream flow was likely to have infiltrated further downstream if taken at a larger scale, thus reducing exposure time to be evaporated.

On the other hand at the Kolwan Valley site, the available storage was a constraint on the amount of additional water that can be recharged since the aquifer was of low storativity. Therefore recharge brought about by the dams has a short transit time since it resurfaces as baseflow. The highest increase in recharge was recorded in the Tamil Nadu site of Kodangipalayan since the aquifer is exploited to such an extent that natural recharge is insufficient to fully replenish the aquifer on an annual basis.

To conclude, MAR proves to be effective at replenishing over-exploited aquifers, and can also be used to control saline intrusion or land subsidence and improve water quality. However it was stressed that it only enhances the volume of groundwater abstracted and can play a role as part of a larger package when it comes to aquifer management, to control abstraction and restore groundwater.

Artificial recharge in Maharshta, India

Dr. Sunil Jain further contributed to the evaluation of managed aquifer recharge technology through his experience of artificial recharge in an overdeveloped watershed in Maharashtra, India. The watershed under study was the Bhaunak watershed which forms a part of the Tapi alluvial belt located within the basaltic Deccan Traps of Maharashtra State. The multidisciplinary study integrated the science of water, land, topography, and climate, as highlighted previously by Mr. Ian Gale.

Most of the area is cultivated (approximately 70%) and a rapid decline in groundwater levels (on average 1m decline per year) had sparked an interest in aquifer recharge possibilities. The over-abstraction of water is due to over 3000 dugwells and 500 tubewells that have resulted in an extensive overdraft and groundwater imbalance. Various aspects of the study were explained in detail by Dr. Jain in order to reveal the significant role each study played in the final evaluation of the scheme. The morphometrical analysis of the watershed revealed that the value of the drainage density often indicates moderate to high permeability and relief in the watershed. The drainage length and slope are also required to define the number of water conservation structures that could potentially be installed in the mountainous area. The role of geomorphology and geology of the area was also studied in significant depth, giving particular attention to the location of major faults and different strata composition within the basin.

Climatological analysis was permitted through daily rainfall and rainfall intensity analysis, together with other weather components such as temperature, wind velocity, relative humidity and the number of sunshine hours. Soil texture and moisture was also studied in order to identify infiltration rates and thus designate areas ideal for the location of percolation tanks. Soil texture analysis is also deemed essential since this ultimately influences what managed aquifer recharge techniques should be chosen and the actual design of such techniques.

Continuous monitoring of percolation tanks and stream flows enabled the construction of a realistic estimate of the catchment yield in different catchments. It resulted that upstream mountainous stream flow was ideal for artificial recharge due to 2 main reasons - silt free clean water and flow available for a considerable period. Such recharge would augment both the quality and the quantity of water. In the lower catchment, higher silt loads were found, thus being inadequate for recharge due to in unreliability as a source and also because of the possibility of clogging any of the recharge structures with silt.

The construction of lithologs contributed towards the greater understanding of the hydrogeological framework and aquifer geometry of the site. It also permitted the realization that surface spreading techniques of MAR, such as percolation tanks, are not feasible in the part of the basin composed of granular and clay horizons. On the other hand MAR structures such as injection wells and recharge shafts were seen to be more appropriate.

Once the groundwater recharge potential was assessed and an impact assessment considering all types of MAR techniques, together with small scale rainwater harvesting through roof top harvesting, was carried out, a groundwater augmentation plan could be derived. Once again community participation was highlighted to be critical to ensure the success of such measures.

Water Quality issues and Rainwater Harvesting

Prof Mike Edmunds elaborated on the significance of evaluating the quality of water when considering rainwater harvesting and its effectiveness. Rainwater harvesting can often provide good quality water in areas affected by water pollution and salinity and thus harvested water may provide an improved and safer supply. However quality problems may arise during the collection and actual storage of rainwater. Rainwater that is collected in a roof tank bypasses the natural mineralizing process and thus may be less acceptable for drinking purposes due to its acidity, low mineralization or due to contamination on storage.

The initial rain water chemical signature is derived from the source of water vapour, primarily the oceans, and contains solutes entrained as marine aerosols, atmospheric dust and any impacts of human activity such as forest fires or industrial emissions. This signature changes as soon as rain comes in contact with the ground. This is because of the uptake of solutes and nutrients. Rainwater is slightly acidic and low in dissolved solids, but on entering the soil it rapidly takes up carbon dioxide through microbiological processes. This helps in the dissolving of minerals. If carbonate minerals are present, the water will become close to neutral because of the buffering created by the carbonate-bicarbonate system.

Some published studies revealed that the quality of harvested rain in some developing countries does not meet the drinking-water guideline values since most water is contaminated microbiologically and thus special care has to be taken during the collection and storage of rainwater. Heavy metals and trace organics may also pose problems.

In the case of groundwater recharge, most of the uptake of solutes in the water takes place in the unsaturated zone due to weathering reactions. This process neutralises acidity and mineral dissolution can be enhanced as a result of the high soil pCO_2 concentrations. As a result, the main properties of water quality are determined in the top few metres.

The quality of artificially recharged water is superimposed on the natural baseline water quality which may or may not differ from natural recharge. However in semi-arid regions baseline quality needs to be assessed since high quality, relatively modern water from artificial recharge may be superimposed on a baseline of older water containing, for example, higher salinity or high fluoride.

Environmental chemical and isotopic tracers are also often used to help demonstrate recharge pathways of recent rainwater recharge and also confirm the efficiency of managed recharge schemes.

Prof. Edmunds mentioned that the most common and simple method was the chloride mass balance (CMB) method to estimate recharge. In this balance the increased salinity (chloride) is proportional to the amount of evapotranspiration and inversely proportional to the amount of recharge (R):

In many semi-arid regions this method has been applied successfully using unsaturated zone profiles, where surface runoff is near-zero. Including surface waters groundwater samples in the CMB approach is more complex but if the sources of Cl are known, an inventory of water inputs and outputs from the catchment or watershed may be involved and the overall efficiency of the recharge scheme should be related to an overall decrease in Cl. It is believed that there is scope for further application of the CMB to estimating the efficiency of rainwater harvesting schemes on condition that appropriate data are collected including that for establishing baseline conditions.

Stable isotopes of oxygen and hydrogen are also potential tracers in evaluating rainwater harvesting. Individual monsoon events may thus have distinct fingerprints that may be traceable into the aquifer. New storms may be distinguishable from previous season's rainfall which may have undergone evaporation and enrichment in the heavier oxygen isotope (^{18}O). This approach needs testing on research catchments but should lead to better understanding of the recharge efficiency in a well characterised watershed, especially if tested with CMB and WTF methods.

A case study on the quality of rainwater was presented for the state of Rajasthan, India, which is considered to be one of the worst-affected states in terms of high flouride contamination of aquifers. There is a high incidence of dental and skeletal fluorosis in the province. The presented case study showed that in low-rainfall areas with potential fluoride problems such as Rajasthan, it is important to assess the hydrogeological situation very carefully. The generation of high-fluoride groundwaters usually requires considerable residence times in the aquifer. Thus, it is likely that younger, shallow groundwaters, for example those recharged rapidly through check dams and stream channels, may have low fluoride concentrations compared with older groundwater. They may be exploitable by skimming the shallow water table rather than abstraction from deeper penetrating boreholes which mix water of different quality.

High fluoride waters have traditionally been treated by a range of techniques. However, village-scale fluoride removal presents drawbacks in terms of removal efficiency, cost, ethical issues, local availability of materials, chemistry of resultant treated water and disposal of treatment chemicals as well as monitoring the process. The harvesting of rainwater, either directly in cisterns, tanks or by careful collection via small recharge dams, offers a potentially safe and attractive alternative solution in endemic areas.

Professor Edmunds then summarized the main factors relating to quality of collected rain in relation to materials and construction ,including roof materials, roof location, avoidance of matter deposited on roofs and avoiding anaerobic decomposition of organic matter. The chemical and microbiological quality of collected water was then considered and how best to avoid pathogens, trace organics, mosqitos and other contaminants

Costs and Benefits of rainwater Harvesting in Iran

Further evaluation of the potential and impacts of water harvesting were given by Dr. Sharifi through his recount of experiences and lessons learnt from rainwater harvesting in Iran. The full account of the cost-benefit analysis described by Dr. Sharifi enabled the participants to clearly see what the potentials and limitations of RWH are in a semi-arid and arid environment, as revealed through Iran. Dr. Sharifi described rainwater harvesting as an inexpensive means of mitigating water supply deficiencies. The cost-benefit analysis carried out revealed that RWH is an economic and efficient method since it results in a large return for relatively small investments. What makes its so attractive economically is its simplicity in technology and thus its applicability that is added impetus in encouraging the community to actively participate in RWH promotion and implementation.

When exposing the vast potential Iran has in terms of water resources, Dr. Sharifi gave estimates from a surface flow analysis, a 30-year rainfall analysis and a groundwater balance analysis. All three studies revealed that the potential water from these water resources was highly significant. For surface flow an estimated additional 260Mm^3 was calculated. The potential yield of water resources in 646 monitored sub-catchments in wet years was higher than 228 Mm^3; whilst the groundwater balance study taken across 3 watersheds in Iran, resulted in an average annual availability of 5 Bm^3.

In view of this, the scarcity in water resources in Iran can be attributed to watershed and aquifer mismanagement. It was pointed out that management of these resources could only lead to important soil and water conservation, which in turn will yield a cumulative positive effect on the maintenance of soil nutrients and organic content, as well as the propagation of plants.

Dr. Sharifi also mentioned the utilization of floodwater as an important solution to the shortage of fresh agricultural water. It was argued that this floodwater can best be stored in mountainous areas due to the reduced evaporation losses in such environments. Flood spreading over coarse-grained alluvial fans also enhances agricultural production and forest reclamation. Over 50% of Iran is mountainous, with very low evaporation capacities and also covered in coarse-grained areas, thus providing the capability of storing water and delaying sub-surface flows. It was stated that if 5 rainfall events occur annually and only 1000m^3 of water is infiltrated, then the total precipitation in a wet year can be completely accumulated in natural reservoirs.

It was also argued that investing in new dams does not make sense since evaporation rates in open reservoirs in high and dams face problems of sedimentation and pollution, thus increasing costs of maintenance. *Also the investment required for each cubic meter of water storage capacity in surface open reservoirs is nowadays 5 to 10 times higher than the capital investment formerly required for similar projects constructed in the past.* Moreover in the face of the uncertainties brought about by climate change the estimated storage capacity of these dams cannot be justified due to fluctuating annual precipitation.

Water Harvesting techniques in the Arab region

Dr Zakri gave an overview of the diversity in water harvesting techniques in the Arab region, explaining the use of structures in Yemen, Sudan, Libya, Tunisia and Egypt. The main point exposed through Dr Zakri's presentation was that water harvesting is central to alleviating water scarcity problems in the Arab region. This explains why diverse water harvesting techniques have been widely practiced in the Arab region dating back over 9000 years.

The catchment area in Arab countries is a major criterion for classifying water harvesting systems as follows:

1. Micro-catchment water harvesting systems where the catchment area and cultivated area are adjacent. Eg. The Negarim microcatchments and contour bunds are examples of this water harvesting technique.
2. Macro-catchment water harvesting systems where the catchment area is located upstream of the cultivated area, permitting the harvesting of overland flow
3. Spate irrigation system which depends on harvesting flood water from wadi channels. This type of RWH technique requires a huge catchment.

Dr. Zakri explained a wide range of RWH systems in the Arab world, some of which were further described by Dr. Noman in the subsequent presentation. A full account of the terraced systems in Yemen and spate irrigation systems in Sudan was given, exposing the ingenious technical and engineering capabilities of these seemingly simple but effective techniques and structures. Of particular interest was the description of the Miskat systems, (or *Meskat/Jessours* in Tunisia), one of the most ancient RWH methods employed. The use of these systems is common in the Arab Maghreb (Tunisia, Morocco and the north-west of Libya in Jebel Nafousa). The Miskat was described to be simply a piece of flat land with a mild slope (3 to 6%) with few or no drainage channels. The land is prepared for rain water harvesting and then water is directed to another piece of land of half its area and located directly below. This parcel of land is called the collector where crops are planted. Water can thus be said, to be stored in the soil horizons. Unfortunately the state of these Miskats has deteriorated because of the intensive agricultural development that took place since the middle of the century.

Two case studies from Egypt were also presented by Dr. Zakri. The first looked at Wadi Watier in south-eastern Sinai. This wadi is characterised by strong flash floods that have put several lives at stake and destroyed several areas which are of historic significance. For this reason 17 retention dams and 5 storage dams have been proposed. The costs of these dams have been calculated to be compensated within a few years after the execution of the proposed control dams.

The second case described the Wadi Ghuweiba, in the Eastern Desert in Egypt. This wadi consists of Eocene limestone outcrops forming a delta. The delta itself is characterized by a gradually sloping irregular surface dissected by fan drainage lines and covered by alluvial deposits, considered as an important source of groundwater in Quaternary sediments that can be withdrawnl by shallow dug wells taking into consideration the sea water intrusion from the Gulf of Suez due to over pumping.

Geoelectrical resistivity sounding was employed to determine the thickness of the layers. From this study it resulted that there two main aquifers in Wadi Ghuweiba area; the upper Quaternary aquifer which can be harvested by drilling wells to a depth of about +150 m, and the Tertiary aquifer which can be harvested by drilling wells of about +450 m.

In order to increase the rate of recharge to the Quaternary aquifer, an artificial recharge system was recommended. Six locations were employed to induce infiltration into the Quaternary aquifer using of instream structures. These structures were series of rechargeable dams which are changing the hydraulic regime of wadi Ghuweiba stream, decreasing flow velocities and encouraging the growth of riparian vegetation..

Review of the water harvesting techniques in Yemen

Dr. Abdulla Noman from the Water and Environment Centre (WEC) of Sana'a University, Yemen gave a comprehensive overview of the various state of the art techniques used in Yemen for using and managing harvested water.

Water collecting catchments are often located away from village cores in order to prevent pollution. Yemen, having historically been one of the oldest civilisations in the Middle East that depended upon agricultural development and thus the main purpose of use of harvested water in cistern structures was for animal watering, drinking and supplementary irrigation. This has permitted Yemen to be self-sufficient in food production for centuries and moreover export its surplus. Changes however, in the lifestyle and consumption patterns of the increasing population has caused the abandonment of terraces and their maintenance and the absence of traditional cooperation among farmers due to both internal and external migration.

Dr. Noman mentioned the production of a local material known as *khadad*, which was and is still used to cement rainwater cisterns. This material has proven to be of high quality due to its resistance against weather elements and the guarantee of its long lasting quality. Further research on the application and production of this material is required.

The variety of rainwater harvesting systems in Yemen include roof top harvesting whereby water is collected in a dug out structure called a *Seqaya*. In hilly areas rain is collected on the roof and directed into an underground storage tank through a settling tank used for domestic use. Terracing is also utilised in the mountainous areas whereby terraced fields provide sufficient time for rainwater to intercept the soil, and low-lying contour built rubble walls prevent runoff but simultaneously permit the water to move down slowly from one terrace to the next through the voids between the rocks in the wall. In addition to terracing, ponds for agricultural use are also used. These can be either excavated farm ponds, embankment ponds or excavated-cum-embankment ponds. Cisterns are also used particularly in the mountainous areas of Yemen. These cisterns are usually underground masonry tanks used for drinking and domestic purposes.

Flood water harvesting and spate irrigation is common practice in Yemen. This technique involves the directing of floodwaters in mountainous areas to coastal and foothill areas. In this way spate irrigation is utilised for the production of major crops. Such a traditionally embedded technique is characterised by a water right given to upstream users over downstream users, such that upstream irrigator's only releases water to downstream users once all the water needs have been satisfied. The irrigator is then obliged to release water to downstream irrigators. Diversion structures used in spate systems are needed to direct large flood waters away from the command area so as not to cause damage. The structures utilised are deflectors or *Al-Qaid* (low earthen bunds); high earthen bunds (*Ogma*); drop structures (*Al Masaqit*) and spillways (*Al Masakhil*).

Water rights are not consistent in Yemen. This implies administrative difficulty when it comes to keeping track of legitimate users. However a person in each area (known as an Al-Moqadem), a local expert, would know the area and land owners very well and thus aid in the understanding of traditional law of water rights.

Dr. Noman ended his presentation by giving his views on the future role of rainwater harvesting. From the Yemen experience appropriate systems can evolve form traditional know how on water harvesting. It was again emphasised that lessons should be learnt from the shortcomings of previous projects. Worldwide the development in rainwater harvesting technologies has aided the scientific and management community to see such technologies as supplemental water systems and combined system that allow the prolongation of the cropping season or even the possibility of growing a second crop. Rainwater harvesting is also seen to have a dual purpose since the first runoff waters can be used to irrigate cropping areas and excess water can then be stored in some facility for later irrigation use. Rainwater harvesting potential to enhance soil water storage is also essential since the water retention capacity of soils has to be high enough to supply crops with sufficient water, especially in dry environments when rainfall is intermittent.

Lastly the importance of a further need for in depth knowledge on the hydrological, pedological and crop parameters is required so that more efficient models could be developed.

Water Harvesting experiences in the Indian subcontinent- The influence of NGOs

The final group of presentations all struck the same chord- the significance of NGOs in the role they play to encourage rainwater harvesting at the community level.

Ms. Kavarana (CSE Delhi) and Mr. Sharma (Wells for India), both representing highly influential organisations gave insight on how local communities can actually be made to feel a part of the implementation of RWH in their own environments.

A case study of the Aravali Hills Rajasthan India was presented by Mr. Sharma. Wells for India is a UK registered Charity that works with poor communities in Rajasthan, India. The charity supports RWH as a primary intervention in community development. The case studies illustrated that safe potable water availability provided by rainwater harvesting schemes not only improve health and releases time and energy of women, but also improves poor people's income, education, as well as social and cultural well-being. Increased water availability through small scale water harvesting structures in *Nayagaon, Jamun and Nala* villages has increased the productivity of crops, fodder and milk production. Local village self-help groups also started playing active roles in the village development issues such as education and health care. The communities are carrying out many activities themselves, enabling to take next step towards better sustainable future.

This work is spread over 11 districts of Rajasthan working with with 22 local non-government organizations (NGOs). Projects are generally based in village clusters in the upland areas of a river basin where resources can be targeted at individual villages. Successful water harvesting intervention in one village often provides the model for adoption and replication in neighbouringneighboring villages.

Results from a 5-year water harvesting project show that RWH is an essential foundation for all other forms of development in a village. Small scale water harvesting work not only helps in increasing water availability but also in enhancing productivity of food grain and fodder and allowing income generation. Local village self-help groups formed in the villages are playing active roles in the village development tackling issues such as health and education. Through water security groups are motivated to carry out a variety of activities, enabling them to take their next step towards better sustainable future.

Rainwater harvesting in the Cholistan Desert, Pakistan

Dr. Mohammad Kahlown of the Pakistan Council of Research in Water Resources gave an interesting overview of the Pakistani experience on rainwater harvesting initiatives that were created in the Cholistan desert, Pakistan.

About 70 million hectares of Pakistan fall under arid and semi-arid climate including desert land. Cholistan is one of the main deserts covering an area of 2.6 million hectares where water scarcity is the fundamental problem for human and livestock populations as most of the groundwater is highly saline. Rainfall is the only freshwater source, which occurs mostly during the monsoon (July to September). Therefore, rainwater harvesting in the desert has crucial importance.

The Pakistan Council of Research in Water Resources (PCRWR) has been conducting research studies on rainwater harvesting since 1989 in the Cholistan desert by developing catchments through various techniques and constructing ponds with different storage capacities ranging between 3000 and 15000 m^3. These ponds have been designed to collect maximum rainwater within the shortest possible time and to minimize seepage and evaporation losses. As a result of successful field research on rainwater harvesting system, PCRWR has developed 92 rainwater harvesting systems on a pilot scale in Cholistan desert. Each system consists of a storage reservoir, energy dissipater, silting basin, lined channel, and network of ditches in the watershed. The storage pond is designed to collect about 15000 m^3 of water with a depth of 6 m. Polyethylene sheets (0.127 mm) on the bed and plastering of mortar (3.81 cm) on the sides of the pond was provided to minimize seepage losses. All these pilot activities to harvest rain have brought revolution in the socio-economic uplift of the community. These activities have also saved millions of rupees during the recent drought. Large scale adoption of all these interventions would ultimately help improve the socio-economic conditions of the residents of hyper-arid area of the country.

3 Conclusions and recommendations

3.1 RECOMMENDATIONS FOR THE G_WADI WEBSITE

3.1.1 Case Study Briefing Reports

1. It is recommended that different categories of topics should be suggested so that the vast range of topics that tackle Rainwater Harvesting, are found by means of quick reference.
2. In the 4-page paper itself instead of ‘take home message’, it was suggested that this subheading should be changed.
3. A template for case studies in G-WADI was discussed and agreed with IAH and the final suggested format is given as Appendix 3

3.1.2 Content of case studies

1. The mode and techniques applied to RWH should be included in the briefing.
2. Each downloadable paper should not be too big in terms of size and thus picture resolution, size and quantity should be reasonable so that files are not too difficult to download.
3. Since the case study is summarised work it was agreed that the total report should not exceed 3-pages.
4. Additional material deemed necessary to enhance the findings of the case study can be included only as appendix form or through the use of external html links.
5. Links can be embedded in both PDF and html/xml form. Cross-links to other databases and websites are permitted provided that permission is always sought from the data provider.
6. A description of both success stories as well as failures should be included as case studies since failures teach valid lessons.
7. A format or template of what is expected from a case study will be provided by agreement between UNESCO and IAH.
8. Exposure on the roles of key stakeholders in the case studies should be given together with the provision of links to enable potential readers to contact these, should they require any further information.

3.1.3 Additional requests regarding the website

1. There was a general consensus for the need of a specialised glossary defining all technical terms used to describe the different RWH structures in the Middle East and Asia, together with any other RWH jargon that the lay person might not fully grasp. This would be completed by an additional round of correspondence, after checking that so far none exisited.
2. A map of the different regions, together with the number of case studies presented for each should be included as the way in to the site.
3. The *Yazd Declaration* is an important background to the Aleppo Workshop and is included as Appendix 4.
4. A rainwater harvesting calculator that facilitates the user to quantify supply and demand and the subsequent size of storage required could be useful and as a tool it would attract users to the site.
5. In relation to the above it was suggested that downloadable models that could be easily accessed by anyone should also be made available.

6. It was suggested that commissioned policy briefs on topics that require coverage and updates could be summarised and made available so that these could be easily utilised by any policy maker.

3.1.4 Upkeep and user-friendliness of website

1. The importance of updating the site was also stressed since this would encourage users to keep using it.
2. To facilitate access and improve popularity the possibility of translation of some parts of the website were also discussed. It was concluded that only the parts of the site that are static and don't change too often can be translated. Alternatively those that do require constant change will not be translated given the budget constraints and difficulties met in the upkeep of the site.

3.2 MEETING CONCLUSIONS AND ACHIEVEMENTS

An Integrated Systems Approach towards rainwater harvesting development and promotion was felt to be the key to several success stories in the region. In defining the key term *integrated,* it refers to the approach of developing rainwater harvesting (RWH) and managed aquifer recharge (MAR) in the light of both water and land management in a watershed. It implies a holistic analysis of land and water management by considering surface, subsurface and groundwater interactions.

RWH and MAR potential should be integrated within a community by means of assessing the physical, climatic and geological potential of these technologies in terms of past present and future changing scenarios; their economic viability in relation to the costs and benefits of developing RWH and MAR and in relation to other alternative water supply technologies; as well as through assessing the social acceptance and government will to promote these. The role of governance was seen to be significant in aiding the integration of RWH and MAR practices into society. The integration of the above would enhance sustainability since sustainable socio-economic development would be enabled.

RWH schemes are often criticised for taking too much of the water at the expense of downstream riparian users. This was challenged in discussion. Where this has been cited (eg in Karnataka India) there is often wholesale capture of surface flows by small dams to create" tanks". The practices advocate by attendees at this meeting were small scale and often completed at the expense of evaporation losses by getting direct rainfall *underground*, not in surface holding structures where evaporation losses were high

There is a need to balance top down (science and technology-led usually) with bottom up approaches; traditional and community approaches with government approaches. This integrated approach needs to be facilitated by Governments.

A. Traditional methods reflected through Country / Region summaries established a need for holistic approaches-

- Short term approaches do not work
- Community involvement is essential such as through self help groups, farmers groups
- Effective governance aids in enhancing community involvement – government will and the interaction with NGOs
- Replication of best practices
- Catchment scale assessment is needed (land and water interactions as well as surface and groundwater interactions)

A 1. The significance of traditional methods was revealed:

(*see also the main points of the Yazd declaration*)

- Rich traditions can engage and renew public interest
- can restore RWH practices together with community involvement
- training and transfer of knowledge at the community level

A 2. The merging of traditional practices and know-how with modern approaches:

- There is a need to consider socio-economic conditions now – these have changed and difficult to go back
- Using traditional knowledge as a base we can enhance and improve simple technologies
- Use the knowledge behind traditional practices as well as additional know-how
- e.g. use of remote sensing for detection of suitable sites and monitoring
- Modelling techniques and their appropriate adaptation
- Modelling of structures and the modelling of physical characteristics of the watershed is necessary, requiring also good field data.

It is not enough to highlight the importance of traditional knowledge; there is a need to change public attitudes to bring this knowledge to the fore and for demonstration projects.

B. An enabling socio-economic environment

After considering traditional techniques and their integration with modern technologies the socio-economic issues were addressed:

B 1. Conflicting nature of water as an economic and public good:

- Water subsidies are an obstacle and disincentive towards water conservation and encourage excess water consumption; however incentives are needed to support RWH structures and RWH implementation at the community level.

B 2. Legal Issues

- Legislation has often been in place over a long time
- Reform and enforcement is necessary

B 3. Education:

- The raising of awareness at all levels of society is needed. Education plays a role in this. Target groups should include children, adolescents and adults alike.
- Information (often grey literature) is required to be disseminated

B 4. Policy

- Need for clear recommendations for policy from science and practitioners
- Interweaving of cultural and religious traditions regarding water

Grass roots involvement – something more than mere consultation

- NGO stimulation of possibilities which eventually become independently run by the community

- Women's role is vital – shifting from water carrying to involvement in self help groups for livelihood improvement
- Poverty alleviation – MDG's (Millennium Development Goals) and equity as basis of sustainability
- Strength of civil society and NGO's vital part in facilitation
- It was also pointed out that there is a need for more in-depth stakeholder interaction, a process which is more complex than mere NGO-Government support.

C. Technological and Scientific Help

- Appropriate rainwater harvesting designs and structures are needed for uptake by modern societies. Design guidelines for RWH and MAR structures are necessary to bridge the gap between traditional know-how and modern technologies.
- Capacity building needed at several levels
- Alternative technologies such as desalination, sewage treated effluent, and grey water re-use should be considered in line with rainwater harvesting or managed aquifer recharge practices, as long as their full environmental and energy costs are considered.
- RWH and MAR structures require monitoring and characterisation – so far lacking in many schemes
- WTF (water table fluctuation) and CMB (chloride mass balance) approaches should be used for tracing and evaluation of recharge efficiencies
- Instrumentation in remote arid regions – expensive and difficult to justify therefore need for remote sensing
- Use of remote sensing for land cover assessments and to predict meteorological conditions
- Long term records of climate change needed to predict and consider sustainability
- Models - promoting what is available and accessible
- Roles of NGO and links with science base
- Demonstration of steady state
- Training manuals available in many countries – accessing them is crucial and a role for G-WADI?
- Water quality issues and baseline indicators

Case Stuy Outcomes

- Need for good case studies – long term
- Control of siltation and vegetation important
- Each structure and site is unique therefore (hydro)geological characteristics are very important
- Does upstream abstraction affect downstream riparians?
- In general RWH offers a safer alternative for drinking water in areas affected by high F or salinity. Occasionally MAR may mobilise F during recharge process.
- Similar structures in many countries - need to intercompare
- RWH improves ecosystems overall, biodiversity, forest regeneration

D. Recommendations

1. Need for a glossary.
2. Defining a methodology to evaluate projects – need for list of indicators, monitoring and valuation of RWH projects
3. RWH and MAR require Environmental Impact Assessments in order for them to be implemented efficiently and effectively in the right places. There is a need to link upstream abstraction with the improvement of ecosystems, biodiversity and forest regeneration for instance. Also there is a need to study the impacts of diffuse or focused recharge in different landscapes.
4. The translation of case study experiences into successful RWH implementation is also needed: Identification of 4-5 project areas to see how the main conclusions can be placed within an RWH implementation framework. A road map towards the appropriate implementation of RWH and MAR is required. Of course this does not imply one size fits all.
5. Issues considered essential which the workshop briefly addressed:
    - The importance of soil water
    - Water use change brought about by agricultural changes and different policies brought about by various governments.
    - The need to have a more general approach towards involving society so that a wider spectrum of potential players is involved.

Appendix 1 Programme and Timetable

19th November

Field visit to sites of water and archaeological interest (Optional)

20th November

13:30 Registration

14:00-14:20 Opening

ICARDA statment	Dr Mahmoud Solh, Director General
UNESCO -G-WADI statment	Dr Abdin Salih, UNESCO Tehran
Meeting background	Prof. Mike Edmunds, Oxford University

14.20-15:10 Overview of participating organizations programmes

14.20 Dr Abdin Salih (UNESCO Tehran)

UNESCO G-WADI programme and IHP

14.30 Dr Zargar (Deputy Minister of Energy for Water Affairs, Iran) and Chairman of ICQHS The International Centre on Qanats and Historic Hydraulic Structures :

A Brief Overview on the Establishment of the International Centre on Qanats and Historic Hydraulic Structures

14.40 Dr Abdallah Droubi (ACSAD)

Overview of ACSAD programmes on Water Harvesting

14.50 Ian Gale (IAH-MAR and British Geological Survey)

International Association of Hydrogeologists MAR programme

15.00 Dr Thieb Oweis ICARDA

ICARDA Programmes relating to water harvesting

15:10 Coffee break

15:30-17:30 Session 1. Historical and Traditional Perspectives

Chair: Prof. Mike Edmunds

15.30 Dr Samsar Yazdi (UNESCO ICQHS Yazd)

A Survey on the Historical Aspects of Qanats in Iran

16.00. Gita Kavarana (CSE Delhi India)

The value of a raindrop. Traditional RWH systems, particularly in the arid and semiarid regions of Rajasthan and Gujarat.

16.30 Dr Theib Oweis (ICARDA)

Indigenous Knowledge: Role in traditional and modern water technologies

17:00 Discussion

20:00 ICARDA Dinner

21st November

9:00 – 10:30 Session 2 Thematic: Environmental and Societal Context

Chair: Dr Abdin Salih

09.00 Professor Howard Wheater, (Imperial College London)

Defining sustainable yields for rainwater harvesting

09.30 Dr Anupma Sharma (National Institute of Hydrology, Roorkee)

Water Harvesting context in the Indian Subcontinent

10.00 Dr A Droubi, Ihab Jnad, Mahmoud Al Sibai (ACSAD, Damascus)

Use of rainwater harvesting for alleviating poverty in rural areas: ACSAD experience in the Arab region

10.30 Claudine Cardona (Malta Water Authority)

Issues relating to RWH implementation in Malta and Mediterranean islands

11.00 Coffee break

11:30- 17:00 Session 3. Case Studies and Modern Practice

Chair: Dr Rasool Zargar

11.30 Ian Gale (IAH) and BGS (Wallingford)

Managed Aquifer Recharge - lessons learned from the AGRAR study, India

12.00 Dr Sunil K Jain (CGWB Delhi)

Artificial Recharge in Semi-arid Region of Maharashtra, India

12.30 Prof Mike Edmunds (G-WADI and Oxford University)

Water quality in the evaluation and effectiveness of RWH and MAR schemes– an overview

13.00 Lunch

14.00 Dr Forood Sharifi (Iran)

The Potentials and Impacts of Water Harvesting Projects in Arid and Semi-Arid Regions (based on lessons learnt from Iran)

14.30 Dr A Droubi, Dr. Mahmoud Sibai, (ACSAD Syria)

Rain water harvesting for combating desertification and rehabilitation of degraded lands

16.30 Dr Abdul Aziz Zakri.

Water Harvesting techniques in the Arab region

17.00 Dr Abdulla Noman (Water and Environment Center, Sanaa, Yemen)

Review of the Water Harvesting Techniques in Yemen

20:00 G-WADI Dinner

22nd November

Session 3. 9:00-12:30 **Case Studies, NGOs and Modern Practice**
Chair: Ian Gale

09.00 Ms Gita Kavarana (CSE Delhi)
Temples of modern India.

09.30 Om Prakash Sharma (Wells for India)
Holistic Approach to Rain Water Harvesting in the Aravali Hills, Rajasthan India

10.00 Gary Woodard (SAHRA Arizona)
Rainwater Harvesting in the American South West

10.30 Coffee break

11.00 Mr Durdy Chuchayev (Turkmenistan)
Title to be advised

11.30 Dr Mohammad A Kahlown – Paksitan
Rainwater Harvesting in Cholistan Desert: A Case Study of Pakistan

12.00 Annuka Lipponen
Other UNESCO projects with a link to water harvesting'

12.30 Discussion

13.00 Lunch

14:00- 19:00 **Session 4: Implementation and committee meeting**
Chair: Prof. Mike Edmunds

14.00 G-WADI implementation. Web site and follow up.

17.00 Ad hoc G-WADI Committee meeting

20.00 Dinner

Appendix 2 Template for RWH Case studies

UNESCO G-WADI is developing a web based set of short case studies demonstrating the applications of water harvesting RWH/MAR (Rain Water Harvesting and Managed Aquifer Recharge) in solving water scarcity problems in arid and semi-arid lands. The purpose of this activity is to disseminate, in a common format, the results of both published and unpublished work in a way that promotes the applications of the science and technology both to other workers but especially to a wider audience and especially a non-technical audience. This activity will also be linked with parallel activities by IAH (International Association of Hydrogeologists) on MAR.

A searchable database of case studies will be developed on the G-WADI web site (http://www.g-wadi.org/casestudies/). Each case study has a maximum of 1000 words and contains only illustrations that are useful for summarising the work and conveying the message to a wide audience. The following headings are proposed:

TITLE (author, date, address, e-mail)

Location

Main water harvesting aim(s) illustrated and social setting

Abstract (50 words)

Hydrogeological, climatic setting

Methodology and results of water harvesting studies

Findings and conclusions. Practical benefits, people affected, environmental, ecological impacts

Credits

Further reading – 2 or three specific references/web links

Two photographs maximum

Two conceptual diagrams (suitable to convey message to wider audience)

Appendix 3 Meeting presentations and photo material index (CD)

Statement Dr Zargar

Dr Semsar Yazdi – Text and PPT presentation

Photographic record of meeting and participants

Abdin Salih UNESCO presentation PPT

Abdallah Droubi ACSAD actities PPT

Abdallah Droubi – Rainwater Harvesting for combating desertification PPT

Abdallah Droubi – Early Warning for Drought mitigation..PPT

Gita Kavarana Presentation PPT

Annuka Lipponen UNESCO activities linked to Rainwater Harvesting PPT

Gary Woodard American Southwest experience in RWH PPT

Gita Kavarana – Water – its in our hands PPT

Anupma Sharma Presentation PPT

Ian Gale – IAH/MAR activities PPT

Ian Gale – AGRAR project PPT

Gita Kavarana – The value of a Raindrop PPT

Howard Wheater RWH papewr PPT

Claudine Cardona – Malta PPT

Thieb Oweis – ICARDA experience PPT

Om Prakash Sharma – Wells for India PPT

Muhammad Kahlown – Cholistan RWH PPT

Mike Edmunds – Water Quality PPT

Farood Sharifi – Iranian experience PPT

Sunil Jain Maharastra PPT

Turkmen PPT

Abullah Noaman – Yemen experience PPT

Abdelaziz Zaki – Arab region and RWH PPT

Appendix 4 2004 Yazd Declaration on Management of Aquifer Recharge (MAR) and Water Harvesting (WH)

We the participants of the ***Regional Workshop on Management of Aquifer Recharge and Water Harvesting in Arid and Semi-arid Regions of Asia****, from Asia, Arab and European regions met in Yazd, Islamic Republic of Iran during 27-30 November 2004, to deliberate and exchange knowledge and experiences on the technical and policy issues on MAR and WH.*

Noting Persia, as one of the first civilizations to introduce sustainable water technologies to the world. Iran hosted the regional workshop at the International Centre on Qanats and Historical Hydraulic Structures at Yazd, and following technical as well as plenary sessions of experts from 12 countries in the region together with international experts have agreed on the following conclusions and recommendations for action:

Recognizing the state of the art with regard to rainwater harvesting and management of aquifer recharge technology:

- *Harvested rainwater is a major additional supply of water, which provides a genuine solution to scarcity, improved quality and improved livelihood in many rural as well as urban areas*
- *There is now increasing regional recognition of the effectiveness of harvesting techniques at different scales, with added benefits of groundwater quality improvement, flood hazard reduction and soil retention.*
- *Sediment migration was identified as a significant clogging hazard that is managed with a variety of techniques*
- *Traditional knowledge and technologies in the region (especially qanats) are shown to be highly effective and their persistence over two millennia provides a model of sustainability. This knowledge needs to be maintained, disseminated and built upon.*
- *There is a need to characterize active groundwater recharge versus palaeo-groundwater using suitable chemical and isotopic tracers as a basis of sustainable management and as a foundation for MAR.*

Noting key policy issues:

- *Integrated water resource management (IWRM) strategies should recognize rainwater as an additional water resource, in addition to surface and groundwater.*
- *Introduce and reinforce appropriate legislation and regulations to ensure demand management as a measure towards controlling water levels and stabilizing abstraction, notably to protect shallow aquifers and ecosystems*
- *The involvement of all stakeholders in planning and decision-making is needed as basis of equity and sustainability over the proposed development of new resources.*
- *There needs to be devolution towards community involvement in water management in favour of small to medium scale ventures involving WH and MAR*
- *Monitoring strategies and protection guidelines must be improved through adaptive governance to detect improvements as well as deterioration in water levels and quality, to undertake appropriate and timely remedial actions.*
- *Case studies of both good and bad practice should be documented for better policy formulation and implementation.*

Recognizing the role of dissemination and training:

- *Need for regional training centres for MAR and WH to pass on basic practical skills, share experience and ensure proper standards. The International Centre on Qanats and Historical Hydraulic Structures in Yazd is seen as a pre-eminent model*
- *Development of material in connection with MAR and WH for formal and non-formal training and general awareness raising as part of school curricula in ecology and sustainable environment and furthermore at all levels of society.*
- *The active role of the media in awareness raising should be encouraged and experience shared*
- *Need for training of trainers for professionals at national levels in various areas related to MAR and WH including the use of chemical tracers and isotopes as well as physical techniques.*
- *Networking of experience via the G-WADI network using UNESCO regional centres and also in conjunction with the IAH MAR Commission.*

Emphasise the regional issues:

- *Iran among several other countries in the region, offers immense capacity for training in MAR and WH and we recommend development of appropriate regional training*
- *Countries in the region should collaborate to develop a new international programme for effective development of the MAR and WH technologies as a possible alternative to large costly storage and transfer schemes. UNESCO should act as the catalyst in the process.*
- *Special attention needs to be given (new projects and training) to those regions and countries in the region where experience of MAR and WH is weak.*

And we the participants:

- *Call upon UNESCO, ISESCO, the International Centre on Qanats and Historic Hydraulic Structures and the Regional Centre for Urban Water Management to work closely with the member states of Asia and the Arab region to launch a regional network and a project on Management of Aquifer Recharge and Water Harvesting related to the IHP's G-WADI network.*
- *Invite international scientific associations to join hands in networking of regional institutions, exchange of success stories within the region and internationally.*
- *Invite related UN Organizations to contribute to the regional project particularly in the area of capacity building and training including the use of tools such as isotopes and chemical tracers in monitoring and estimation of recharge and effectiveness of MAR schemes.*
- *Invite funding agencies such as the Global Environmental Facility to support actions related to regional projects.*

Yazd

30th November 2004

Appendix 5 Participants list

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Appendix 6 Meeting Papers

Dr Abdallah Droubi (ACSAD)

Overview of ACSAD programmes on Water Harvesting

Ian Gale (IAH-MAR and British Geological Survey)

International Association of Hydrogeologists MAR programme (see main text)

Dr Samsar Yazdi (UNESCO ICQHS Yazd)

A Survey on the Historical Aspects of Qanats in Iran

Gita Kavarana (CSE Delhi India)

The value of a raindrop. Traditional RWH systems, particularly in the arid and semiarid regions of Rajasthan and Gujarat.

Professor Howard Wheater, (Imperial College London)

Defining sustainable yields for rainwater harvesting

Dr Anupma Sharma (National Institute of Hydrology, Roorkee)

Water Harvesting context in the Indian Subcontinent

Claudine Cardona (Malta Water Authority)

An Integrated Approach towards Assessing the Feasibility of Domestic Rainwater Harvesting in Malta

Ian Gale (IAH) and BGS (Wallingford)

Managed Aquifer Recharge - lessons learned from the AGRAR study, India

Dr Sunil K Jain (CGWB Delhi)

Artificial Recharge in Semi-arid Region of Maharashtra, India

Prof Mike Edmunds (G-WADI and Oxford University)

Water quality in the evaluation and effectiveness of RWH and MAR schemes– an overview

Dr Forood Sharifi (Iran)

The Potentials and Impacts of Water Harvesting Projects in Arid and Semi-Arid Regions (based on lessons learnt from Iran)

Dr A Droubi, Ihab Jnad, Mahmoud Al Sibai (ACSAD, Damascus)

Use of rainwater harvesting for alleviating poverty in rural areas: CSAD experience in the Arab region (Abstract only)

Dr Abdul Aziz Zaki.

Water Harvesting techniques in the Arab region

Dr Abdulla Noman (Water and Environment Center, Sanaa, Yemen)

Indigenous knowledge for using and managing water harvesting techniques in Yemen

Om Prakash Sharma and W M Edmunds (Wells for India)

***H*olistic Approach to Rain Water Harvesting in the Aravali Hills, Rajasthan India**

Dr Mohammad A Kahlown – Paksitan

Rainwater Harvesting in Cholistan Desert: A Case Study of Pakistan

ACSAD activity in the field of water resources management and rainwater harvesting.

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Introduction

The Arab region is located in one of the driest area of the world. The average annual precipitation is less than 100mm in about 70 % of the region (fig.1). Per capita water availability has decreased from about 2500m^3 a year in the middle of the last century to less than 1000m^3 at present .Water scarcity is considered as one of the key challenges to agriculture and water development in the region.

ACSAD as a regional organization has implemented several activities for supporting the countries of the region in their efforts to overcome the water crisis and ensuring sustainable agriculture development; these activities are summarized in the following paragraphs.

1. Rainwater harvesting for the rural poor

Rainwater harvesting is considered very crucial for rural development where water resources are severely depleted and optimal use of precipitation is warranted. The challenge with this issue is to ensure that rainwater harvesting structures are managed in such a way that they are sustainable and they provide equitable water share to all the poor. Based on this objective ACSAD has implemented in cooperation with GTZ (German technical cooperation agency) a rainwater harvesting project in the Western mountainous area in Syria where the poverty in some villages is well developed.

The area is characterized by Mediterranean climate with high precipitation in winter season (precipitation averages more than 1000mm/y) and dry summers. But due to the geological conditions (predominance of karstified limestone) the area is suffering from shortage of water in summer time (absence of aquifers which can retain infiltrated rainwater). So, the local population depends on their survival on rain fed agriculture. Some of them for increasing their economic income are conducting additional agriculture activities in summer time (using high income crop varieties), buying water for irrigation at a very high price. The region is characterized also by very small cultivated areas. ACSAD intervention was concentrated in an integrated package described as follows;

- Building a hill reservoir for storing rainwater with a capacity of 7000m^3 (fig.2) Helping the local population in providing them with crop varieties mainly wheat with high productivity and early maturing for avoiding any freezing .
- Provide the local population with high income crop varieties (like medicinal plants) to be cultivated in summer time so they can increase their economic income and consequently alleviate poverty.
- Training the local population to handle them self the management of the rainwater harvesting structure and share the water in equitable manner between them.

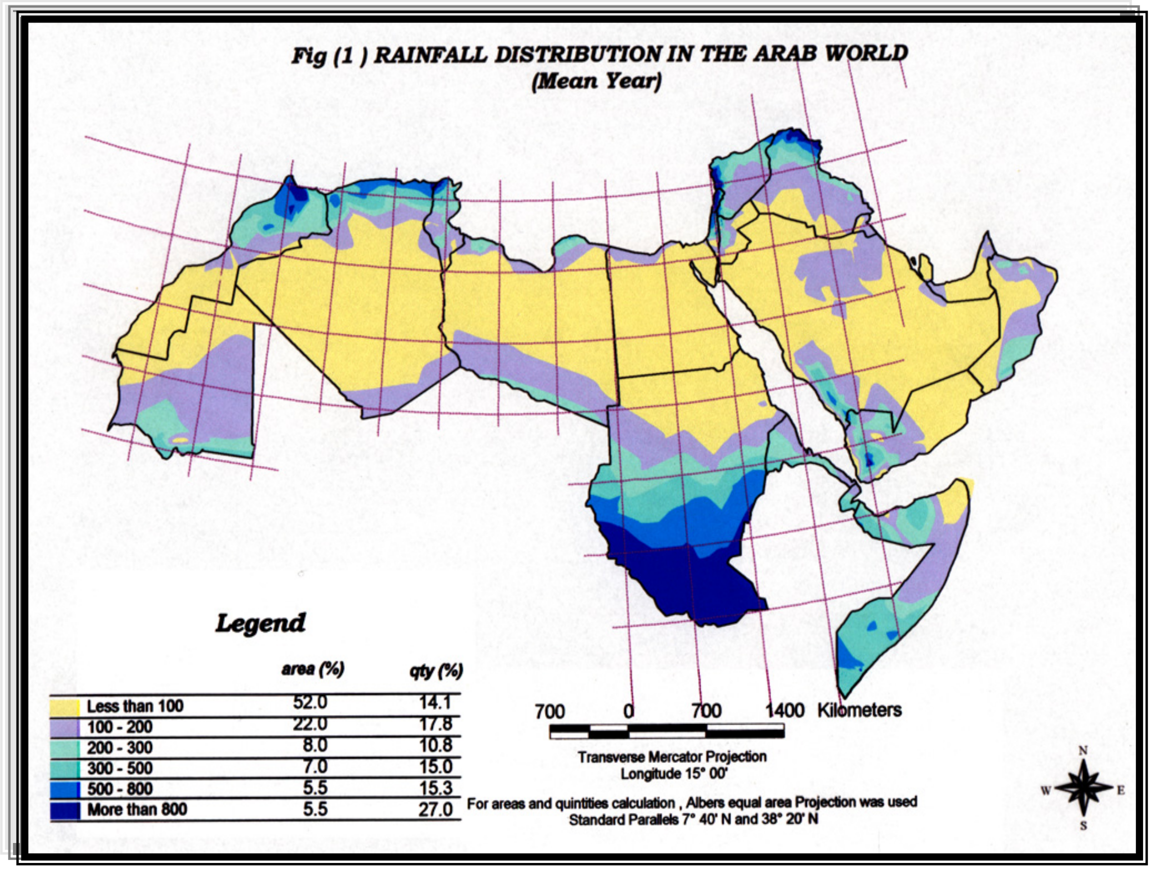

Figure 1. Rainfall distribution in the Arab region

The results of the first year of the project was very encouraging, the productivity of the new wheat varieties introduced by ACSAD has doubled the production with very good quality. Depending on that they requested for the new season another quantity The availability of water in summer time has helped them to give supplementary irrigation for some summer crops such as tobacco, vegetables which has helped them to increase their economic income.

Based on this very successful experience ACSAD started to implement a new rainwater harvesting project in another area of the same region by building three hill reservoirs with a total capacity of 60000m^3 ACSAD also intended to extend this experience to other countries of the region.

2. Water resources management in arid areas

About 25% of agriculture activities in the Arab region is based on irrigation .One of the major elements for defining crop water requirements is the estimation of evapotranspiration, which usually is obtained through the application of FAO formulae. Meanwhile a new method has recently been developed for measuring directly the evapotranspiration using the flow energy budget and eddy covariance method. Such technique has been applied by ACSAD in an EU funded project in Palmyra area, Syria.

Very sophisticated equipment has been installed in Palmyra Oasis (fig.3) over 5 years of monitoring and research study using different methodology (eddy covariance, Penman Monteith and TDR soil moisture measurement). The result of such research has shown that the FAO formula give an overestimation of the evapotranspiration by more than 30%. This means that by using the new technique more than 30% of water required for irrigation may be saved, which could be a grand volume for arid zones. This methodology has also been used for measuring the direct evaporation from the Sebkhat El Mouh near Palmyra. The hydrogeological studies have shown that a great volume of deep groundwater is evaporated through the sebkhat. The idea was to confirm the results of previous hydrological studies which gave two values of great difference. The first based on classical hydrological balance has estimated the evaporation from the sebkhat to be about 58 million cm/year.

The second one based on lysimeter and isotopic techniques gave a value in the order of 27 million cm/y. It was very important to check which is the correct value for planning the exploitation of the aquifer from which the water was evaporated (fig.4) .After 3 years of scientific investigation using eddy covariance methodology it was found that the main source of water evaporated coming from the surface water and floods arriving to the sebkhat during winter time (the evaporation rate is maximum) and the lower evaporation rate is in summer time. The other important result was that the volume evaporated is estimated to be about 30million cm/y.

Another activity conducted by ACSAD is building a decision support system (DSS) for water resources management. Such a system is considered a very valuable tool for helping decision makers for ensuring sustainable water use. The project is conducted by ACSAD in cooperation with BGR (Germany) and implemented in two pilot areas in Syria and Morocco. Such system is very helpful in areas which are facing a shortage of water and where competition between different water users is very high and subject to conflict.

The free DSS software known as WEAP21 which was developed by the Stockholm Institute for Environment, based in Boston USA, has been chosen to be used as a platform for the project. The new development in the system which was conducted through the present project is to link the WEAP21 system to MODFLOW modeling software and build an inter-linkage between both systems. Thus any request for increasing water supply from an aquifer asked to DSS could be tested using groundwater modeling (MODFLOW) and vise versa. (fig.5).

This project will be ended by April 2007 and the final results of the project, including the developed software will be freely distributed to all interested institutions in the Arab countries. The year 2007 will be used for project results dissemination through organizing workshops and training activities**.**

3. Rainwater harvesting for combating desertification

Within the framework of UNCCD action program the West Asian countries have developed a *Sub-Regional Action Programme (SRAP) to Combat Desertification and Drought in West Asia.*

This SRAP/UNCCD pilot project to combat desertification was commenced in February 2003. Initially, a pilot area in Yemen is representing the mountainous areas, and a pilot area in Syria represents rangelands. ACSAD within its responsibility in TN2 (management of vegetative cover) and having a lead role in Syria and Yemen pilot areas provided the technical, coordination and management support to the project. The project implementation follows the multi-disciplinary and participatory approaches within an integrated watershed management framework. The project was completed by the end of year 2006.

The pilot area in Syria is located at Thlaithowat site, Al Bishri Mountain – Syrian Steppe, 90 km west of Der Alzzor. The area is suffering from severe land degradation due to cultivation and overgrazing. There are different degradation processes acting strongly in the area such as wind erosion, sand dust storms, and to a lesser extent water erosion and over-grazing. The area of the pilot project is about 7000 ha, and it is physiographically composed of undulating lands with some gently sloping plains. There are also some valleys running towards the south and southeast. The dominant soil is calcareous with a light texture and a weak structure. The surface of the soils is covered with sand deposits in some locations. Several rainwater harvesting techniques have been tested such as, Contour furrows, Diamond-shaped basins, Semi-circular bunds.

For the rehabilitation of degraded vegetative cover the activities undertaken were:

- *Comprehensive protection for 3 years***:** This method is used in the area with vegetation cover density 40.3% (slightly degraded land of the total area of the site).
- *Direct sowing***:** This method used in the area with medium vegetative cover which represent 41.4 % of the total area
- *Planting of seedlings***:** This activity was carried out in the area characterized with severe and medium degraded area using contour furrow.

- *Forest tree:* forest trees were planted in the depression areas in the site which occupy 5 ha of the project area.

As a result 80 % of the area regenerated its vegetation cover. Morovere, there was great decrease in the rate of wind erosion in the SRAP pilot area. The amount of eroded soil material was reduced from 9448.2 kg/ha in 2003 to 96.77 kg/ha in the August 2006.

3.1 Some policy recommendations to protect the grazing area:

It should be clear that there is no one solution for all environmental degradation problems. The study of the local situation and taking into consideration traditional knowledge of local communities and their participation in all activities is essential to any successful actions.

Education, awareness building can play a role in monitoring and rehabilitation of degraded lands. Agricultural extension work can play important role in preventing environmental degradation. For these policies to be effective they should be part of a wider package. The achievement of sustainable use of dry lands natural resources is dependent on policies and strategies that concern good governance, the environment, rural development, public services, gender equality, science and technology and motivation of the local population (fig.6- a and 6- b).

3.2 Yemen pilot area

Mountainous areas in Yemen have a special importance within the agricultural production systems in the country. Although the rainfall is often high, due to their inaccessibility mountainous areas tend to be the most isolated and marginalized areas. These mountains are home to some of the poorest communities in the region. The complex landscape of the mountainous areas consists of steep slopes, terraced croplands, sloping rangelands, and scattered patches of shrubs and trees. Most of the agriculture depends on direct rainfall, but irrigated agriculture takes place along the banks of the wadis. The degradation in mountainous areas includes severe soil erosion by water run-off on unprotected slopes, which in extreme cases can lead to silting of wadis, loss of agricultural land downstream, degradation of natural vegetation, and depletion of biodiversity.

Agriculture in mountainous areas of Yemen was developed centuries ago based on intricate systems of man-made terraces. The degradation of the indigenous terraces in the Yemeni mountains is now well documented. Poor maintenance and runoff management are believed to be the major cause of mass soil erosion that occurs as a result of the successive collapse of terraces. Terraces require continual maintenance, which incurs a high cost. If an individual terrace is abandoned or not maintained, it can cause the collapse of the entire system. Steep topography coupled with relatively higher rainfall, is another factor that in the absence of appropriate measures for sustainable natural resource management, contributes to soil erosion and other types of land degradation. As a result of the pressure on land resources to meet the demand of the an increasing population, the traditional soil and water conservation systems are threatened by changes in cropping systems and farming practices, intensive use of natural vegetation, overgrazing and deforestation. If current trends continue, much of the mountainous areas of Yemen may permanently lose a significant portion of its productive land to soil erosion. While controversial crops (*qat*), low mechanization, high labor cost, and poor accessibility contribute to degrading conditions, the exploitation of monsoon rain, natural springs, new cash crops and land tenure arrangements could be used to conserve and maintain the resource base.

The Ramaa pilot area located about 80 km north west of Lahjj provinces in Yemen Republic .Al – Rama region is a narrow plain, situated on plateau surrounded by two mountain ranges to the north and south. The area is surrounded by a number of secondary watersheds in the center of Subih valley. The topography of the area is characterized by moderate slopes (15- 20 %), steep slopes (30 – 40 %) and very steep slopes (>50 %). The altitude of the site ranges between 1200 and 1700 m a.s.l. Constructed terrace systems are dominating in the area fig(7). The total population in the project area is about 3774 inhabitants. Agriculture is the main income source for the local people. Major crops grown in the area are corn and millet in the summer and wheat and barely in the winter. The average annual rainfall ranges between 350 and 500 mm. There are two main rain seasons: summer season

(June, July, August) and winter season (January, February). In general, the project area suffers from drought and water resources shortage. Therefore, the entire cropping systems in the area are rain fed. Water for domestic use is brought from remote places using animals and humans.

4. Activities taken in the Yemen pilot area

Due to the scarcity of water the inhabitants prevented the technical team from carrying out any rehabilitation of degraded terraces before providing water for domestic supply. Therefore, a reservoir with a size of 115 m^3 was constructed to collect water from the surface of polyclinic building. The reservoir construction was done with the participation of local communities. (fig.8). A total of 240 m of terrace were rehabilitated at ten farmer's field (fig.9).

5. Lessons learned

- Rehabilitation of degraded steppe land can be achived within three years when the vegetative cover is more than 32 %. The vegetation cover can be regenerated as high as 80 %.
- The topography variation in the area to be rehabilitated is very important for water harvesting.
- 12-meter spacing for contour furrow method was the best for regeneration of vegetative cover for land with slope of 4-5 %.
- The diamond and semi circle water harvesting were found to be excellent water harvesting techniques for forest trees growing.
- For slightly and moderately degraded land, protection with minimal interventions can result in regeneration of vegetation cover within three years.
- Soil material eroded by wind can be accurately measured by BSNE instrumentation
- Rehabilitation of the pilot area reduced the eroded material from 448 kg/ha in 2003 to 98 kg/ha in 2006.
- 65 % of the eroded soil particles by wind erosion has a diameter less than 0.05mm. This indicates that the eroded soil it came from the soil surface which is very fertile as shown by analysis of N, P, K.
- The rehabilitation of degraded terraces is very well taught to the local communities and engineers in Lahj provinces.
- Water harvesting from the building's roof with appropriate design and construction can save up to 95 % from the rainfall.
- Field days, workshops found to be good tools for dissemination of field work on the rehabilitation of degraded land.
- Determining of the appropriate grazing capacity of the rehabilitated land is necessarily to preserve land from degradation.
- Applied measures of rainwater harvesting and plant seedling found to be successful in areas with average annual rainfall ranges between 120 mm and140 mm.

6. Recommendations

- The outcomes of the project were very promising; therefore, workshops should be held in other west Asia countries to disseminate the obtained results from this project.
- More emphasis should be given to sustainable land management. Any measures and interventions taken for land and vegetation cover rehabilitation will not be effective without proper management.
- In Syria rangeland is communal land and is managed by the public sector; therefore, training courses are recommended to teach technical staff in charge of this rangeland on different measures for land and vegetation rehabilitation and management.

- In Yemen, the major problem in mountainous area is water shortage. Water harvesting techniques from roof top proved to excellent techniques to provide additional water resources; therefore, itis recommended to conduct workshops and training courses to spread such technique.

A Survey of the Historical Evolution of Qanats in Iran

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1. Introduction

In order to review the situation of qanats in the course of the Iranian history, this paper explores some documents on qanats from the first historical records to the present ones. Two periods, before and after Islam, have been investigated. In terms of each period we try to review the situation of qanats keeping pace with the history of kings and governments.

First of all, it seems necessary to present some facts on the geographical and climatological conditions of Iran, for the natural infrastructures had an important role in creating and developing the qanat systems. Suffice to say Iran has a variable climate, and in general, this country has an arid climate in which most of the relatively scant annual precipitation falls from October through April. In most of the country, yearly precipitation averages 250 millimeters or less. The major exceptions are the higher mountain valleys of the Zagros and the Caspian coastal plain, where precipitation averages at least 500 millimeters annually. In the western part of the Caspian, rainfall exceeds 1000 mm annually and is distributed relatively evenly throughout the year. This contrasts with some basins of the Central Plateau that receive 100 millimeters or less of precipitation annually.

2. Before Islam

Henry Goblot explored the onset of this technology for the first time. He stipulates in his book entitled “Qanat; a Technique for Obtaining Water” that during the early first millennium before Christ, for the first time some small tribal groups gradually began immigrating to the Iranian plateau where less precipitation was enjoyed than the territories these groups came from. They came from somewhere with a lot of surface streams, so their agricultural techniques used to require more water which was out of proportion to the water available in the Iranian plateau. So they had no way but fastening their hope on the rivers and springs that originated in the mountains. They faced two barriers; the first was the seasonal rivers which were out of water during the dry and hot seasons. The second was the springs that drained out the shallow groundwater and fell dry during the hot seasons. But they noticed some permanent runoffs flowing through the tunnels excavated by the Acadian miners who were in search of copper. These farmers established a relationship with the miners and asked them to dig more tunnels in order to supply more water. The miners accepted to do that, because there was no technical difficulty for the miners in constructing more canals. In this manner, the ancient Iranians made use of the water that the miners wished to get rid of it, and founded a basic system as named qanat to supply the required water to their farm lands. According to Goblot, this innovation took place in the western north of the present Iran and later was introduced to the neighboring area that was Zagros Mountains.

According to an inscription left from Sargon II the king of Assyria, in 714 BC he invaded the city of Uhlu lying on the NW of Uroomiye lake that belonged to the territory of the Urartu empire, and then he noticed that the occupied area enjoyed a very rich vegetation even though there was no river running across there. So he managed to discover the reason how the area can stay green, and realized that there are some qanats behind the matter. In fact it was Ursa the king of the region who had rescued the people from thirst and turned Uhlu into a scenic and green land. Goblot believes that the Medeans and Achaemenians were responsible for the spread of the technology of qanat from Urartu (in the western north of Iran and near the present border between Iran and Turkey) to all over the Iranian plateau.

2.1 Achaemenian Empire (550-330 BC)

It was an Achaemenian ruling that in case someone succeeded in constructing a qanat and bringing groundwater to the surface in order to cultivate, or renovating an abandoned qanat, the tax he was supposed to pay the government would be waived not only for him but also for his successors up to 5 generations. During this period, the technology of the qanat was in its heyday and it even spread to other countries. For example, according to Darius's order, Silaks the naval commander of the Persian army and Khenombiz the royal architect managed to construct a qanat in the oasis of Kharagha' in Egypt. Beadnell believes that the qanat construction dates back to two distinct periods. In Egypt some qanats were constructed by the Persians for the first time, and later Romans dug up some other qanats during their rule over Egypt from 30 BC to 395 AC. In any way the magnificent temple built in this area during Darius' reign shows that there was a considerable population depending on the water of qanats. Ragerz has estimated this population at 10000 people. The most reliable document confirming the existence of qanats at this period has been written by Polibius who stipulates that: "the streams are running down from everywhere at the base of Alborz mountain, and people have transferred too much water from a long distance through some subterranean canals by spending much cost and labor".

2.2 Seleucidian Era (312-250 BC)

During the Seleucidian Era that began after the occupation of Iran by Alexander, it seems that the qanats were abandoned.

2.3 Parthian Era (250 BC – 150 BC)

In terms of the situation of qanats during this era, some historical records have been found. In a study done by Russian oriental scholars it has been mentioned that: the Persians used the side branches of the rivers, the mountainous springs, wells and qanats to supply water. The subterranean galleries excavated to obtain groundwater were named as qanat. These galleries were linked to the surface through some vertical shafts which were sunk in order to get access to the gallery to repair it if necessary.

According to the historical records left from the ancient times, the Parthian kings did not care about the qanats the way the Achaemenian kings and even Sassanid kings used to do. As an instance Arsac III one of the Parthian kings destroyed some qanats in order to make it difficult for Seleucidian Antiochus to advance further while fighting him.

2.4 Sassanid Era (226-650 BC)

The historical records left from this time indicate a perfect regulation on both water distribution and farmlands. All the water rights were recorded in a special document which was referred to in case of any transaction. The lists of farmlands - whether private or governmental - were kept at the tax department. During this period there existed some official rulings on qanats, streams, construction of dam, operation and maintenance of qanat, etc. The government proceeded to repair or dredge the qanats that were abandoned or destroyed by any reason, and construct the new qanats if necessary. A document written in Pahlavi language[1] pointed out the important role of qanats in developing the cities at that time.

3. After Islam (621-1921 BC)

In Iran, the advent of Islam that coincided with the overthrow of the Sasanid dynasty brought about a profound change in religious, political, social and cultural structures. But the qanats stayed intact, because the economical infrastructures such as qanats were of great importance to the Arabs. As an instance, Lombard reports that the Moslem clerics who lived during the Abbasid era such as Abooyoosef Ya'qoob (death 798 AC) stipulated that whoever can bring water to the idle lands in order to cultivate, his tax would be waived and he would be entitled to the same lands cultivated. Therefore, this policy did not differ from that of Achaemenians not getting any tax from the people

[1] an ancient branch of Persian language that was spoken during Sassanid era

who revived the abandoned lands. The Arabs' supportive policy on the qanats was so successful that even the holy city of Mecca gained a qanat too. The Persian historian Hamdollah Mostowfi writes:

"Zobeyde Khatoon (Haroon al-Rashid's wife) constructed a qanat in Mecca. After the time of Haroon al-Rashid, during the caliph Moghtader's reign this qanat fell into decay, but he rehabilitated it, and the qanat was rehabilitated again after it collapsed during the reign of two other caliphs named as Ghaem and Naser. After the era of the caliphs this qanat completely fell into ruin because the desert sand filled it up, and later Amir Choopan repaired the qanat and made it flow again in Mecca."

There are also other historical texts proving that the Abbasids were concerned about qanats. For example, according to the "Incidents of Abdollah bin Tahir's Time" written by Gardizi, in the year 830 AC a terrible earthquake struck the town of Forghaneh and reduced many homes to rubble. The inhabitants of Neyshaboor used to come to Abdollah bin Tahir in order to request him to intervene, for they fought over their qanats and they found the relevant instruction or law on qanat as a solution neither in the prophet's quotations nor in the clerics' writings. So Abdollah bin Tahir managed to bring together all the clergymen from throughout Khorasan and Iraq to compile a book entitled "Alghani" (The Book of Qanat). This book took up all the rulings on qanats which could be of use to whoever wanted to judge a dispute over this issue. Gardizi added that this book was still applicable to his time, and everyone made references to this book.

One can deduce that during the above-mentioned period the numbers of qanats were so considerable that the authorities were prompted to put together some legal instructions in terms of qanats. Also it shows that from the ninth to eleventh century the qanats that were the hub of the agricultural systems were of interest to the governments. Apart from The Book of Alghani which is considered as a law booklet focusing on the qanat related rulings based on the Islamic principles, there is another book about groundwater written by Karaji in the year 1010. This book entitled Extraction of Hidden Waters takes up just the technical issues associated with qanat and tries to answer the common questions such as how to construct and repair a qanat, how to find a groundwater supply, how to do levelling, etc. Some of the innovations described in this book had been brought up for the first time in the history of hydrology, and some of its technical methods are still valid and can be applied in the qanat construction. The content of this book implies that its writer (Karaji) did not have any idea that there was another book on qanat compiled by the clergymen. Mohammad bin Hasan quotes Aboo-Hanifeh that in case someone constructs a qanat in an abandoned land, someone else can dig another qanat in the same land on the condition that the second qanat would be 500 zera' (375 meters) away from the first one.

Ms. Lambpton quotes Moeen al-din Esfarzi who has written the book Rowzat al-Jannat (the Garden of Paradise) that Abdollah bin Tahir (from Taherian dynasty) and Ismaeel Ahmed Samani (from Samani dynasty) had several qanats constructed in Neyshaboor. Later in the 11th century a writer named as Nasir Khosrow acknowledged all those qanats by the following words:

"Neyshaboor is located in a vast plain at a distance of 40 Farsang (~240 km) from Serakhs and 70 Farsang (~420 km) from Mary … all the qanats of this city run underground, and it is said that an Arab who was offended by the people of Neyshaboor has complained that; what a beautiful city Neyshaboor could become if its qanats would flow on the ground surface and instead its people would be underground".

These documents all certify the importance of qanats during the Islamic history within the cultural territories of Iran.

In the 13th century, the invasion of Mongolian tribes to Iran lead to many qanats and irrigational systems falling into ruin, and many qanats were deserted and dried up. Later in the era of Ilkhanid dynasty especially at the time of Ghazan Khan and his Persian minister Rashid Fazl-Allah, some measures were taken to revive the qanats and irrigation systems. There is a book entitled Al-Vaghfiya Al-Rashidiya (Rashid's Deeds of Endowment) that names all the properties located in Yazd, Shiraz, Maraghe, Tabriz, Isfahan and Mowsel, Rashid Fazl-Allah has donated to the public or religious places. This book mentions many qanats running at that time and irrigating a considerable area of farmlands. At the same time (14th century) another book entitled Jame' al-Kheyrat was written by Seyyed Rokn al-Din on the same subject of that of Rashid's book. In this book Seyyed Rokn al-Din names his properties in the region of Yazd donated. These deeds of endowment indicate that a lot of attention was given to the qanats during the reign of Ilkhanids, but it is attributable to their Persian ministers who had influence on them.

In the Safavid era (15th and 16th century) the problem of the shortage of water intensified and led to constructing many water reservoirs and qanats. Sharden the French explorer who made two long journeys to Iran at the time of Safavid reports that:

"the Iranians rip the foothills in search of water, and when they find any, by means of qanats they transfer this water to a distance of 50 or 60 kilometers or sometimes further downstream. No nation in the world can compete with the Iranians in recovering and transferring groundwater. They make use of groundwater in irrigating their farmlands, and they construct qanats almost everywhere and always succeed in extracting groundwater."

The dynasty of Qajar ruled Iran from the 16th century to the early 18th century. According to Goblot, the time of Qajar can be considered as the heyday of qanats, for the qanats could flourish. Agha Mohammad Khan the founder of Qajar dynasty chose Tehran as his capital city, the city where there was no access to a reliable stream of surface water and it had to rely on the groundwater. The rich supply of groundwater and suitable geological-topographical conditions of Tehran allowed this city to house many qanats whose total discharge amounted to 2000 liters per second. Haj Mirza Aghasi (ruling between 1834 and 1848) the prime minister of the third king of Qajar dynasty encouraged and supported qanat construction throughout the country[2]. Jaubert de Passa who has surveyed the situation of irrigation in Iran reports a population of 50000 in Hamedan, 200000 in Isfahan and 130000 in Tehran in the year 1840. Then he claims that in these cities life is indebted to the qanats which are being constructed in a simple but powerful manner. In a nutshell the period of Qajar that lasted about 1.5 centuries has witnessed lots of endeavors to revive the qanats.

3. The period of Pahlavi

During the period of Pahlavi, the process of qanat construction and maintenance continued. A county that was responsible for the qanats was set up by the government. At that time most of the qanats of the country belonged to the land lords. In fact feudalism was the prevailing system in the rural regions. The peasants were not entitled to the lands they worked on, but they were considered just as the users of the lands. They had to pay the rent of the land and water to the feudals. The feudals could afford to finance all the proceedings required to maintain the qanats, for they were at a high financial level. According to the report of Safi Asfiya who was in charge of supervising the qanats of Iran in the former regime, in the year 1942 Iran enjoyed 40000 qanats with a total recharge of 600000 liters per second or 18.2 billion cubic meters per year.

In the year 1961 another report was published revealing that in Iran there were 30000 qanats out of which just 20000 qanats were still in use with a total output of 560000 lit/se or 17.3 billion cubic meters per year. In 1959 a reform program named as White Revolution was declared by the former Shah. One of the articles of this program addressed the land reform that let the peasants take ownership of a part of the feudals' lands. In fact the land reform dashed the lords' hope. They lost their motivation for investing more money in constructing or repairing the qanats which were subject to the land reform law. On the other hand, the peasants could not come up with the money to maintain the qanats, so a lot of qanats gradually got deserted. The introduction of the modern devices that made it possible to drill many deep wells and extract the groundwater much more quickly and easily aggravated the qanats' annihilation. The pumped wells had a negative impact on the qanats due to

[2] According to a famous story, one day Haj Mirza Aghasi paid a visit to a qanat to find out how they are getting on their work. He asked the worker who was at the bottom of a well if the qanat had reached to the water or not. The worker who did not recognize the prime minister complained that Haj Mirza Aghasi is wasting the country's budget on the qanats that will never have water. The minister replied: "don't worry! if the qanat will not get us water, but will get you a living". The minister's word has turned into a popular proverb in Iran.

their overexploitation of the groundwater. These changes that occurred in Mohammad Reza Shah's reign inflicted a great damage on the qanats of the country so that many qanats vanished forever. The statistics related to 14778 qanats estimates the overall discharge of these qanats as 6.2 billion cubic meters per year between the years 1972 and 1973. If we assume the total number of the qanats at that time to be 32000, so their annual discharge could amount to 12 billion cubic meters.

In the year 1963 the Ministry of Water and Electricity was established in order to provide the rural and urban areas of the country with the sufficient water and electricity. Later this ministry was renamed as the Ministry of Energy. Three years later in 1966 the Parliament passed a law protecting the groundwater resources. According to this law the Ministry of Water and Electricity was allowed to ban drilling any deep and semi-deep wells wherever the surveys show that the water table is dropping because of overpumping. In fact this law was passed when the growing number of the pumped wells sounded the alarm about the overpumping and depletion of groundwater leading to the decline in the qanats' flow all over the country. This law as well as the law of water nationalization that was approved in 1968 and eventually the law of fair distribution of water passed (in 1981) after the Islamic revolution emphasized the definition of the restricted and free areas for drilling. In the restricted areas drilling any wells (except for drinking and industry) were prohibited in order to prevent the continuous depletion of groundwater. So the rest of the qanats had a better chance to survive.

3.2 The time of the Islamic Republic

After the Islamic revolution, special attention was given to the qanats. For the first time in 1981 a conference on qanats was held in Mashhad during which the different options to mitigate the problem were explored. The organization of Jihad Sazandegi took responsibility for the qanats and provided the users of qanats with some funds. Now the same organization which was renamed as Jihad Agriculture is responsible for the qanats and continues to grant some funds to the stakeholders to maintain their qanats. During recent years, the parliament has allowed an annual budget of 13 million USD to go to the construction and maintenance of the qanats. Many other qanats may dry up without this budget, because the owners of the qanats cannot afford to pay the whole expenses.

In the years from 1984-1985 the Ministry of Energy took a census of 28038 qanats whose total discharge was 9 billion cubic meters. In the years 1992-1993 the census of 28054 qanats showed a total discharge of 10 billion cubic meters. 10 years later in 2002-2003 the number of the qanats was reported as 33691 with a total discharge of 8 billion cubic meters. In the year 2000, holding the International conference on qanat in Yazd could draw a lot of attention to the qanats.

4. Conclusion

In the course of Iranian history, the qanat has had many ups and downs. Sometimes the qanats as well as the qanat constructers were supported and encouraged by the governments, and sometimes were deserted by them. Even when the qanats were destroyed for some military purposes, the qanat would start flourishing as soon as the political situation became stable. The risks that are threatening the qanats today differ from those in the past. In other words, in the past the political and military crisis had a negative impact on the qanats, however the qanats could recover as soon as the crisis was over. But the present risks are quite something else, and more destructive. The present risks are acting environmentally so it is not that easy to handle them. Therefore it is a must for the governments and nations throughout the world to think of new legislation for the protection of groundwater resources against any kind of over exploitation.

Qanat civilization is rooted in this ancient hydraulic structure. Over the past 3000 years, the system of qanat has underlain many technological, social, moral, economic and legal principles that have formed an important part of our culture. These principles evolved into the present state by being passed from generation to generation. The present generation is supposed to build on these principles behind which there are three thousand years of history, not to forget about them.

The value of a raindrop. Traditional RWH systems, particularly in the arid and semiarid regions of Rajasthan and Gujarat.

1. The water crisis

Everyone talks about the world's water crisis. What is the crisis all about? In very simple terms, you could say that the world's resources of freshwater remains fixed even as the population that uses it continues to grow (or it will grow for sometime to come). At the same time, the processes of industrialisation, agricultural modernisation and urbanisation place enormous demands on the world's water resources even while polluting the available water.

At the start of the 21st century, 49 countries with around 35 percent of the world population were believed to have less than 2 000 cubic meters of renewable freshwater available per capita per year (WRI, World Resources 2000-2001, 2000). As more and more countries are facing water shortages, they are resorting to food imports. For instance, North Africa and the Middle East were the fastest growing import markets for grain in the 1990s (Serageldin, quoted in Population Reports, 1995).

Yet the crisis facing us is not one of water scarcity, but one of water management. Providing water to all the people, sustainably and equitably, is the most critical challenge that the world faces today. But this challenge can be met through judicious and rational water management. There are many ways to meet this challenge: technological solutions, fiscal solutions, and legislative solutions. All these are very necessary; however, they also need enormous political will, discipline within the society, and huge financial and technological resources.

The answer lies not only in modern technology and management systems, but also in our traditions.

2. Rationale for rain water harvesting

The art and science of catching water where it falls is an ancient wisdom, but one which is dying. This traditional wisdom of catching and using rainwater was widespread across Asia and Africa, the most water-stressed regions today. This wisdom, if revived and reinforced with modern science and technological inputs, can help in meeting modern water needs.

Governments across the world are following models of water development that focus on harnessing surface and groundwater that require huge investments in financial and technological resources. Today, research shows that much of these investments are, in fact, very inefficient or even counter productive. According to a UNEP report, in the top five irrigating countries of the world (India, China, USA, Pakistan and USSR), almost 24% of the total land under irrigation was damaged due to salinisation and over irrigation in the 1980s.

Water withdrawals from rivers and underground reserves have grown by 2.5 to 3 percent annually since 1940 (Postel et al., Science, 271: 785, 1996). It is expected to grow by 10-12% every 10 years till 2025 (UNESCO, 1999). For instance, Libya, uses 7 times more water annually for irrigation than it receives in rainfall by pumping "fossil" water from deep beneath the Sahara desert. India is using groundwater at twice the recharge rate, causing some water tables to fall by between 1 and 3 meters a year (Worldwatch Institute, Vital Trends 1999-2000, 2000).

In this scenario, harvesting rainwater makes eminent sense. For instance, in India, although there is a total precipitation of 4000km^3 annually, it loses almost 1700 km^3 as evaporation, soil moisture etc, which can be captured and utilised. More importantly, the value of water harvesting lies in the fact that it need not be the responsibility of the governments, and it can be executed by communities using simple technologies and resources, available locally. Traditional wisdom realised that every last man or woman not only has water needs, but can also contribute to the management of this resource. Water harvesting is a cooperative enterprise -- it serves to bring communities together.

3. Potential of water harvesting

The potential of water harvesting is enormous. For instance, in an area of one hectare, assuming a bare minimum annual rainfall of 100mm, one can still collect, at minimum, more than a half-million litres of water.

Region	**Rainfall level**	**Potential of yield from 1 hectare of land (10000 m^2)***	**Population density**	**Land availability**	**No of people whose water needs can be met at 75 litres/day/person**
Rural-arid	100m	0.6 million litres	Low	High	22
Rural-humid	1500m	9 million litres	High	Low	329
Urban	600m	3.6 million litres	High	Low	132

* Assuming a collection co-efficiency of 60%

Dr. P.R. Pisharoty, eminent physical scientist in India, estimated that water captured in just 3% of the total land area of India would yield nearly 900 km3 of water even at collection efficiencies of 50-60%. Given the fact that the National Water Commission has estimated the total water demand of India in 2025 to be 1093 km3, you can understand the importance of capturing and using rainwater. It means that theoretically rainwater harvesting alone can fulfil almost the entire water demand of India even by 2025.

4. Traditions of water management in India

Historians have described India as a 'hydraulic' civilisation. Even when the British came to India about 250 years ago, there were a number of urban settlements built on riverbanks (Patna, Varanasi and Allahabad); and others built around tanks and lakes (Jodhpur, Jaisalmer, Bhopal). Tens of thousands of water structures of diverse technologies existed all over the country, with diverse management systems to ensure equitable and sustainable water supply to all. Structures built to trap and manage rainwater were specific to the terrain and meteorological conditions. Technologies were usually simple, and harnessed local materials and labour. Over time, rainwater harvesting structures were woven into the region's cultural and religious milieu.

The history of water harvesting in India goes way back to Vedic times. Archeological excavations of the Indus Valley civilisation at Dholavira, dating back to 3000 B.C, in the Great Rann of Kutch, showed a sophisticated system for harvesting rainwater. This is the earliest example found anywhere in the world. This arid region had little rainfall, no perennial sources of water and the groundwater was brackish. The excavations showed stone bunds built across two streams to divert monsoon runoff through a network of drains into several large reservoirs built in the city. Several stormwater drains also collected rainwater.

Though India is well endowed in terms of rainfall, (annual average rainfall of 1160mm), this rainfall comes in just over 100 hours in the year. Ancient India had learnt to plan for the remaining 8660 hours without any rain. In the hill and mountain regions, people diverted spring water into channels or dykes (*kuls, guls, kuhals*) to bring water for irrigation. In the arid central highlands and the western parts of the country, people dammed water from small catchments to moisten the soil and increase groundwater (*khadins, johads, chaukas, pats*). In the south they built a series of tanks to divert water from rivers (*eris, keres*). In the floodplains a system of canals and reservoirs diverted surplus flood waters to be used later. In Madhya Pradesh, for instance, the invading Mughal rulers built a *qanat* in Burhanpur, to tap the groundwater aquifer.

This paper will focus more on the traditional water harvesting systems in the arid regions of western India.

5. Rainwater harvesting systems in the arid region of Rajasthan and Gujarat

5.1 Traditional urban water harvesting systems in the Thar Desert

The Thar Desert is described as one of the most inhospitable regions of the world and is almost a rainless desert. Some areas do not receive more than 120 mm of annual rainfall. Yet this desert is the most densely populated desert in the world. It has been continuously habited for over 1200 years. A number of urban centres developed, but always in locations that had easy access to water. The people of this region made sagacious use of natural resources, particularly water to sustain human and livestock populations.

In the desert towns of Jaisalmer and Bikaner, traditionally, large catchments supplied water to tanks. The catchments and the canals were regularly maintained and kept clean. Rooftop harvesting was common in cities and towns of Rajasthan. Rainwater collected from roofs was taken to underground tanks, called *tankas*, built in the courtyard or in the house. The *tankas* were sometimes as large as a room.

A *talab* is a local reservoir made out of natural depressions on outcrops of hillocks or rocky formations. Usually, only the slope side of the reservoir or *talab* was provided with strong parapet walls. Tanks are different from *talab*s, in that they are constructed *in situ* with impermeable floor and massive masonry stonewalls on all sides. Tanks held an important place in cities of Rajasthan and Gujarat. Jodhpur, Udaipur, Bhuj, Jamnagar, Anjar are some of the cities, which, till recently were supplied water principally from tanks and lakes. People also constructed lakes on the outskirts of cities to provide water to the populace. For instance, the famous Pichola Lake in Udaipur was built by the nomadic *banjaras*, and not by the rulers. Water was usually brought through a system of canals from the catchments outside the city.

Step wells were another way of harvesting rain and providing drinking water in the arid parts of the country. In these parts, rivers and other surface water retain water only for a short time and stepwells are often the only source of drinking water. These have a unique form of underground architecture and have been in use in parts of Rajasthan and Gujarat since the 7^{th} century. In Rajasthan, they are known as *baolis* or *bavdis* and in Gujarat they are known as *vav* or *vavadi*. Larger stepwells have up to 7 storeys underground. There were many forms of stepwells with variations in architecture.

The city of Jodhpur provides an excellent example of diverse ways of harvesting rainwater. A plateau that runs through this region acts as the main water catchment to numerous tanks and lakes and also indirectly for groundwater bodies such as wells. There were over 200 water bodies in all, many of them over 500 years old. The city's 40-odd *talab*s in the city still exist today and many of them are over 300 years old. The Ranisar and the Padamsar *talabs*, built by the erstwhile Jodhpur kings, are still used for drinking and other purposes. But urbanisation is destroying the catchment of these *talab*s. The seepage water from large *talab*s fed a large number of wells and *baoris*. The city has an intricate system of groundwater bodies – wells, *baoris* or community wells used for drinking, *jhalaras* or community wells not used for drinking.

Jodhpur had 5 massive tanks, constructed in the last two centuries, to supply water to the city. These were used until 1955 for drinking and were maintained by the municipality. While three of them have been destroyed and abandoned, two have become polluted with the city's sewage. Jodhpur also had an excellent system of lakes located on the outskirts of the city. There are five lakes, which together, could hold about 700 million cu. ft. of water. Again, destruction of the catchment areas and the canals mean that today they hold very little water. A fascinating system of channels, aqueducts, and watercourses linked the water bodies in the city with distant catchments and also distributed water within the city. A survey revealed that Jodhpur had a total canal length of about 85 km.

5.2 Traditional rural water harvesting systems

The arid states of Rajasthan and Gujarat also developed an intricate system of harvesting rainwater for irrigation, livestock and drinking water in the rural areas. There were a range of systems to suit diverse needs and climate and geological conditions – *nadi, tanka, toba, talab, kund, kui, virdas* and so on.

Nadi was the name given to a village pond, a natural surface depression, which receives rainwater from an adjoining natural catchment. Every village had its own *nadi* and the location of the *nadi* had a strong bearing on the storage catchment and runoff characteristics. While *nadis* in dune areas were shallow and had heavy seepage losses, those in alluvial areas were large, capable of storing water for much of the year. A study undertaken by the Central Arid Zone Research Institute (CAZRI) showed that the number of *nadis* in the towns of Nagaur, Barmer and Jaisalmer numbered 1436, 592 and 1822 respectively.

Toba is a system similar to the *nadi,* a ground depression with a natural catchment; it also had grasses growing around it to provide pastures for livestock. The *toba* served as the main pasture ground for the traditional pastoralists. *Kunds* are found in the western arid regions of Rajasthan and some are more than 400 years old. In these areas, groundwater is brackish or saline and *kunds* holding sweet rainwater were usually the only source of drinking water. These structures are often up to 6m deep and have a dome-shaped cover. Each *kund* has an artificial catchment, often made with lime plaster or cement, which is maintained and cleaned before the onset on monsoon rains. These structures were community or individual-owned. In some places, families own up to 500 *kunds*.

Kui, also known as *beri*, was another system, which was built near tanks to catch the seepage from the tanks. These were mainly rough structures and were used as an emergency source of water when all else failed.

Khadin, another clever system, is used even today in agriculture in the Thar Desert. This is very similar to systems used by the people of Ur (Iraq), the Nabateans and the inhabitants in the Negev desert. It involves harvesting rainwater in farmlands. *Khadin* consists of an embankment built across a slope in such a way that rainwater is collected within an agricultural field. This method of embankment moistens the soil and prevents loss of topsoil. It was provided with systems to drain off excess water. *Johad*, similar in principle, are earthern structures built on fields and grazing lands to store monsoon rains, and to increase percolation into the ground. Tarun Bharat Sangh, an NGO working in the Alwar district of Rajasthan, worked with rural communities to build numerous *johads*, bringing dead rivers back to life.

Virdas is an interesting system developed by the nomadic Maldhari tribes who inhabit the arid-saline regions of the Rann of Kutch. This unique system speaks volumes of the ingenuity and adaptive capacity of the local people. As this area is very saline, rainwater, when it infiltrates the soil, collects in a layer above the saline groundwater, being less dense. The *maldharis* identify the natural depressions (*jheels)* from the flow of the monsoon runoff, and then dig small wells *(virdas*), within the depression, to collect rainwater. The wells lie over the top of the saline layer, with a transition zone of brackish water between. Bushes and trees, planted on the bunds, protect the *virdas*.

6. Decline of traditional water harvesting systems

Traditional water management was underpinned by the following:

- There was no water bureaucracy. Rulers did not build water structures except for their own needs. People were expected to build structures for themselves or for their communities.
- People were encouraged to do this through fiscal incentives. As taxes were levied as a proportion of farm produce, the rulers had a vested interest in good agricultural yield. Thus, they provided grants by way of tax exemption for a period to those interested in building water harvesting structures.
- Finally, there was total transparency and everybody was informed of the details of such grants/gifts, the beneficiaries, the period etc. In south India, even today, you can find these details as inscriptions on temple walls.

With the advent of British rule in India, there were three major developments.

1. The first was that the British introduced a taxation system that impoverished the peasantry and many became landless and destitute. The result was that many of these systems became defunct.
2. Secondly, the British built a centralised bureaucracy, which neither understood the technological rationale of these systems nor could manage the diverse and decentralised systems.
3. Thirdly, the British did not realise the nature of India's monsoons, which comes in a short spell, and built systems based entirely on surface water, that were more suitable for a climate that had uniform rainfall throughout the year.

The worst thing was yet to come: the British educated an entire class of people, who would follow in their footsteps. Thus, independent India's water bureaucracy followed the models laid down by the British and all the Five Year Plans focussed on building big dams for irrigation. The people of the Thar Desert were promised, and given, water from Sutlej and Beas rivers. The people who had lived within the confines of the natural water sources for centuries, no longer wish to exert themselves to build systems to harvest rainwater. They do not even want to maintain the existing ones, given the fact that water comes at the turn of a tap. In a similar manner, the people of Gujarat are clamouring for the waters of Narmada, although, the tanks and wells that harvested rainwater had served them well for centuries.

Over the years, the rainwater harvesting systems that needed communities to work together, disappeared, and was replaced by state (and now increasingly, privately) sourced water. The deep bore well technology of the 1970s only exacerbated the situation. Groundwater is being ruthlessly mined, even as systems to recharge the same groundwater are destroyed. The nation's urge to develop has taken a severe toll on India's natural resource base. Developmental activities like mining, deforestation and urbanisation have destroyed the catchments across the country.

Thus, almost 60 years after independence, India's water bureaucracy is still making water vision plans around concepts of building dams or digging deep. Today, if you take a look at the water resources planning of any state government you will find that the plans revolve around bringing water from sources more than 400 km away or digging deep Raneywells that go more than 200 m deep to supply water at per capita levels of more than 260 l/person/day to city dwellers.

7. Case studies

Scattered over India's rural countryside are inspiring stories of those who are rediscovering the power of community in overcoming the water crisis -- with water as the starting point, not only the environment, but also the economy could be regenerated.

1. <u>1970s: Transformation of Ralegan Siddhi</u>

In the late 1970s, the pioneering village of Ralegan Siddhi initiated participatory land-water-forest management. Ralegan Siddhi was a destitute village in the early 70s with high levels of distress migration and extreme poverty. The average annual rainfall ranges from 450mm to 600mm and villagers were not even assured of one crop. In 1975, the village was in the grip of poverty, and had hardly one acre of irrigated land per family. Food production was only about 30% of the requirements and there was a high level of distress migration.

Anna Hazare, a retired army jeep driver who is today a well-known environmental crusader, involved villagers to start regenerating their environment. He began by constructing storage ponds, reservoirs and gully plugs to catch the rain and moisten the soil. At the same time, he made use of government schemes for watershed management, afforestation to plant numerous trees. The groundwater level slowly began to rise and cultivable land area began to increase. The biggest contribution came from the villagers in the form of free labour (*shramdan*). The villagers do not take any grant from any donor except to make use of government schemes.

In 1998, CSE commissioned a survey to study the ecological transformation in Ralegan Siddhi, which showed stunning economic results. *The top 27 per cent of the households in this village had an* *annual household income of more than Rs. 4,80,000 (approximately $ 12,000) a year*. The village had a branch office of a major bank with nearly Rs. 3 crore ($ 750,000) in deposits of villagers. Given the fact that in 1998 there were only 1 million households in India who earned more than Rs. 1 million ($ 25,000) a year, including estimates of black money (according to the National Council of Applied Economic Research), this is an absolutely outstanding achievement, built entirely on good land-water management.

The reason why Ralegan Siddhi is known the world over and is a model for others is because of the institutional mechanisms that the villagers have created. Some 14 committees (registered as societies) exist to ensure people's participation, and each committee looks after a specific part of the natural resource management work. These different societies are accountable to the *gram sabha* (village committee), comprising of all the villagers. Watershed activities are undertaken only after they are discussed in the *gram sabha* in detail on the location, the cost-benefit etc.

2. Bringing rivers back to life in Alwar

Tarun Bharat Sangh (TBS) began work in the villages of the Aravali hills situated in the highly degraded parts of Alwar district in the mid-1980s. TBS just did one thing, which was to encourage villages to make traditional water harvesting structures to catch the water and allow it to percolate and recharge the groundwater wells. In 1986, TBS built 3 small earthern *johads*, on agricultural fields that would hold rainwater, moisten the soil and also irrigate the fields. The effort of Gopalpura in Alwar attracted so much attention that within 10 years, TBS had helped villagers to build nearly 2500 such structures in over 500 villages in the region. As a result of this, numerous hill streams, which were earlier dead and would never see any water in them, now flow round the year and agricultural production has increased. And people have slowly started protecting the hills and greenery is returning to this once highly degraded region.

Till 1997-98, the water conservation structures built by communities in Alwar had cost Rs. 15 crore (Rs. 150 million), of which the people contributed Rs. 11 crore (Rs. 110 million) in cash or kind. It is clear that it is the villagers themselves who are making the maximum contribution. In each village detailed discussions are held by the *gram sabha*. The *gram sabha* makes rules on distribution of water, the kind of crops to grow, the cutting of trees and on maintenance of structures. A study conducted by Dr. G.D. Agarwal, former head of department of civil engineering at the Indian Institute of technology, Kanpur, showed that the structures were extremely cost-effective –ranging from a low of Rs. 0.2/ (US cents 0.4) cubic metre of storage capacity to a high of Rs. 3 (US cents 7)per cubic metre and an average of Rs. 0.95 (US cents 2.2) per cubic metre. In the villages covered by the study, the annual per capita income rose from a low of Rs. 126 (US $ 2.95) to a high of Rs. 3,585 (US $ 83.98). The study found that an investment of Rs. 1000 on *johads* raised economic production by over Rs. 4200/annum.

What is stunning is that, just after 3 years of making these structures along the dead and dry courses of streams in the hills, the rivers have started coming to life. Two seasonal rivers, Arvari and Ruparel have become perennial. A villager who had worked with Tarun Bharat Sangh to make a small dam in his village says that he had not been able to cultivate his land for over 50 years. Soon after independence, after the Raja of Alwar had sold off the local forests, all the wells had dried up. He then became a migrant and went to Delhi. With his well full of water again, only last year, for the first time in 50 years, he has been able to cultivate his land once again in 1997 and his sons are also now working with him. There is no migrant in his family any more.

3. 1990s: Labour of love in Laporiya

Laporiya, a village of pastoralists, located in Jaipur district of Rajasthan, was barren and denuded in 1970s. Today, it is a green land with adequate water for irrigation, domestic purposes and livestock. In 1990, a group was formed (Gram Vikas Navyuvak Mandal, Laporiya) to regenerate the degraded land around the village. Villagers contributed voluntary labour (*shramdan)* to build a system of *chaukas* to spread rainwater regenerate almost 50 hectares of pasturelands.

The *chauka* system involves harvesting rainwater in rectangular plots of land (*chaukas*) to regenerate the pastureland. When it rains and the water rises, it flows into the next *chauka* and so on filling the entire pastureland. At the same time, the *chaukas* are so designed that water stays only up to a certain height that will allow the growth of grass. The system promotes the recharge of groundwater and even at the height of summer, when the grass all but dies, the roots remain, and spring back to life with the first rains.

Moving beyond the pastures, the villagers got together to repair the tanks in the village, which were in a state of neglect. They also built two more percolation tanks and a well for drinking water. In 1996, there was a bumper crop, and, for the first time in 20 years, wheat was grown in the village. Agricultural production rose 12 times and because of this, villagers named this tank, *Anna Sagar*, meaning 'sea of food grain'. In the year 2000, when the monsoons failed in Rajasthan for the third time, there was enough water for drinking and livestock.

4. 1990s: Changing the moonscape to greenery in Jhabua

Even more heartening is the participatory watershed development programme undertaken by the Madhya Pradesh government in 1994, which today covers nearly 10,000 villages. Inspired by Ralegan Siddhi, the MP government showed that even the government is capable of intervening to promote public participation in environmental management.

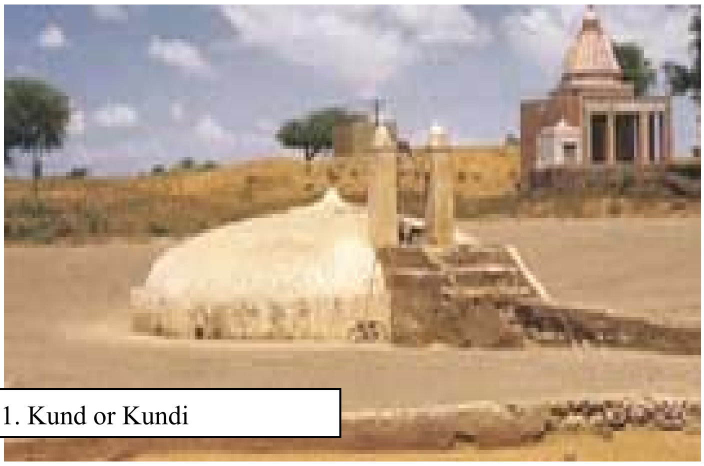
The state-wide programme is today being run in all 45 districts, covering 6253 watersheds in 8692 villages. The programme covers 4.2 million hectares, which is a little more than 1% of India's total land area. The total investment in the programme for the past ten years has been Rs. 1042 crore (US $ 231.6 million), which works out a little over Rs. 4000/hectare.

The impact of this programme has been particularly remarkable in Jhabua, which resembled a moonscape in the 1980s. Once a heavily forested area, Jhabua lost its natural wealth over the last 50 years. More than 30% of its forest lands stood without any tree cover. The reasons were many – government aided plunder of forests by contractors, clearing up for agricultural activities, free grazing and population pressure. The district was dotted with rock-exposed hillocks. This forest degradation meant that the impact was felt most by the tribals who form 83% of the population. After 1960, there was more than one famine and even a food riot in Jhabua.

As a first step to arrest the water falling on the slopes, small tanks were built on the slopes to hold the water. In barely 4 years, water level rose by 0.64m on an average in 19 microwatersheds. The irrigated area doubled to 1115 ha in 18 microwatersheds. The area of wastelands reduced by 66% and the cropped area increased by 7%. Availability of fodder too increased.

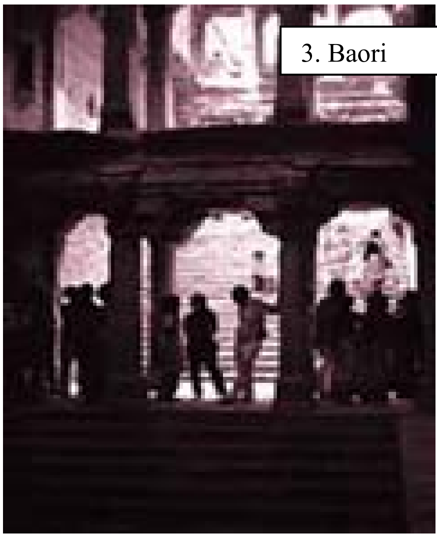
Overall, in the state, *kharif* area has increased by 22.44% and *rabi* area by 49.2%. Fodder production has grown by almost 56%. Income generated by self help groups is Rs. 461.03 lakh (US $ 1.02 million) and savings by thrift groups is Rs. 350.5 lakh (US $ 0.78 million).

The most important aspect was that the programme was participatory and the villagers were actively involved even in managing the funds for the programme. The project established multi-level coordinating committees made up of all stakeholders including the villagers -- firstly, at the state level, for policy coordination; secondly, at the district level and micro-watershed level, for implementation and coordination; and, finally, at the village level to ensure village participation. In Jhabua district alone, 3550 user groups, 1658 self-help groups and 1277 women's groups have been created. Most importantly, efforts have been made to empower local communities with decision-making authority. Nearly 80% of the funds for the programme are put in a bank account managed by the Watershed Development Committee made up of villagers.



1. Kund or Kundi

2. Kui



3. Baori

4. Jhalara

5. Khadin

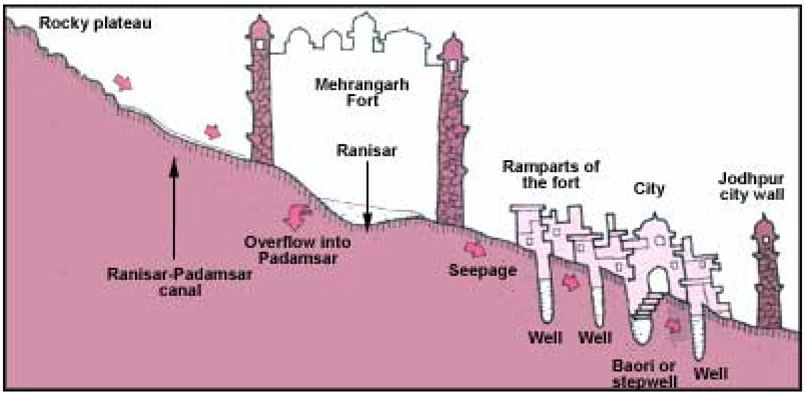
Johad

6. Virdas

Fatehji ka talab, Chittor fort

Jodhpur's water bodies

Ranisar talab, Jodhpur



Defining sustainable yields for rainwater harvesting

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Abstract

The paper discusses the special characteristics of rainfall, runoff and groundwater recharge in arid areas and identifies the challenges to define sustainable yields for rainwater harvesting systems. Rainfall is commonly highly variable in space and time, which has led, for example, to the use of dispersed surface water storage systems to support nomadic agriculture. Many rainwater harvesting systems rely on exploitation of groundwater, augmented by active recharge of surface water. This depends on the integrated management of surface water and groundwater systems. To quantify sustainable yields requires assimilation of rainfall variability, runoff processes and surface water-groundwater interactions. A distributed modelling framework to achieve this is described, with application to the assessment of sustainable yield of recharge dams in the Sultanate of Oman.

1. Introduction to rainwater harvesting

Rainfall harvesting is a term that is widely used, but encompasses a range of very different techniques and technologies, applied across a wide range of scales. At its simplest, it describes the direct capture of rainwater as surface runoff. This may be runoff from roofs and paved areas, harvested at the scale of an individual household for domestic use, surface runoff from small natural catchments, directed to cisterns or tanks for community use, or spate flood flows diverted from a wadi channel to irrigate whole fields. Rainwater harvesting is also used to describe the modification of hydrological response, to provide additional water for subsurface storage. At a local scale, terracing or micro-catchments may be used to reduce surface runoff and increase infiltration to increase available soil moisture for agricultural use. Alternatively, at catchment scale, groundwater recharge can be enhanced and/or focussed – for example through the use of 'recharge dams' to retain or retard surface water flows so that infiltration can be enhanced and/or directed to recharge an aquifer system.

2. Sustainable yields and rainfall temporal variability

While much attention has been focussed on methods of rainfall harvesting, and their local performance, relatively little consideration has been given to the sustainable yield of rainwater harvesting systems. For simple systems, such as the capture of roof runoff, sustainable yield will depend primarily on the temporal variability of rainfall. However, rainfall in arid areas, although by definition limited in amount, is in addition characterised by extreme variability. Where convective rainfall predominates, storm intensities can be high - it is not uncommon in Arabia or the South West of the USA for rainfall in a single storm to exceed the average rainfall for a year (Wheater, 2006). Inter-annual variability is also high; mean annual rainfall is often not a meaningful indicator, and persistent sequences of dry years can occur. For simple rainwater harvesting systems to provide a sustainable resource, therefore, the intermittency of rainfall and its inter-annual variability must be recognised within a frequency-based approach to drought risk and reliability. To accommodate drought, simple systems of surface runoff storage will in general need to be seen as one element in a more comprehensive set of water supply options.

3. Managed groundwater recharge

Given the high potential evaporation rates that occur in arid areas, the most attractive large-scale options for increasing available water generally make use of the available subsurface storage in aquifer systems, and there is increasing interest in, and development of, groundwater recharge management systems. For example, the Sultanate of Oman has, over the last 20 years, invested in recharge dams on the Batinah coastal plain of Northern Oman. These storages are designed as dams with restricted discharge outlets to retain water behind the structure and slow the downstream transmission of flood water. Thus groundwater recharge is focussed both behind and immediately downstream of the dam. In the case of coastal aquifers, such structures capture runoff that otherwise may have been lost as surface runoff to the sea, and the enhanced recharge is important in combating problems of saline intrusion. In other locations, the ability to focus recharge creates the opportunity to enhance a resource at a location that may be of interest due to the availability of aquifer storage or of local demand. To assess the sustainable yield of such systems is complex. Management options must be evaluated at catchment scale, so that any redirection of resource can be considered in the context of existing sources and associated water rights, and a number of important technical issues arise.

4. Spatial variability of catchment-scale hydrological response

For rainwater harvesting applied to the larger spatial scales it is necessary to understand the spatial variability of response of surface water systems, the underlying groundwater response, and the interactions between surface water and groundwater. Groundwater quality considerations may also be important. For a detailed review of hydrological processes, see Wheater et al. (2006); a brief summary of relevant issues is presented below.

Comprehensive monitoring of surface and groundwater systems is relatively rare – or at least is relatively rarely reported in the published literature. However, there are notable exceptions, particularly the long-term densely monitored Walnut Gulch catchment in Arizona, USA (see for example, Osborn et al., 1979, Lane et al., 1971, Goodrich et al., 1997). In the Middle East, the Five Wadis Representative Basins Study in the South West of Saudi Arabia, undertaken in the 1980s, deployed networks of climate, rainfall, flow, soil moisture and groundwater recorders. The most striking result was the picture that emerged of the spatial variability of the predominantly convective rainfall. Rainfall was intense, of short duration, and highly localised in space (Wheater et al., 1991a,b), generating runoff on partial areas of the catchment even on days of relatively widespread rainfall. Surface runoff was focussed in alluvial wadi channels, and transmission losses from surface routing provided infiltration to recharge alluvial groundwater. Thus floods would tend to decrease in volume as the flood peak progressed downstream. These responses are very similar to those observed from Arizona, and the combination of rainfall spatial variability and transmission losses explains the well known property of arid zone catchments of decreasing runoff yield with increasing catchment area.

Clearly, attempts to quantify the potential for water harvesting through managed aquifer recharge in this environment requires that the spatial characteristics of rainfall, and hence runoff generation, are recognised, as well as the surface water-groundwater interactions that determine transmission loss and managed recharge.

5. Defining sustainable yields for managed groundwater recharge

In a study of the potential resource yields from a proposed recharge dam in a wadi system in Northern Oman, Wheater et al. (1995) developed a modelling framework to capture the spatial variability of rainfall, runoff generation and groundwater recharge. This required a stochastic rainfall generator that was developed empirically from the available raingauge network (modelling the probability of rainday occurrence and the conditional distribution of rainfall spatial occurrence and depths by sampling from the population of observed events). This was used with a specially-developed rainfall-runoff model that used SCS curve numbers to generate the spatial distribution of runoff (with parameter spatial distributions developed from soils and geology) and flow routing in the wadi channel network, including transmission losses (after Jordan, 1977). In principle, such a model could then be combined with a groundwater model to represent aquifer response. Within the distributed rainfall-runoff model, it was possible to explore the response to recharge dams of different sizes and locations, for a sequence of years of stochastically-generated daily spatial rainfall inputs. Hence the potential yields of alternative designs could be evaluated in a risk-based framework, considering for example yield for drought sequences of differing severity.

6. Concluding discussion

For simple small-scale rainwater harvesting systems, the definition of sustainable yields will depend on evaluating rainfall variability within and between years, with sequences of drought years being of particular concern. For larger-scale rainwater harvesting systems, the spatial patterns of runoff generation and resulting transmission losses are also important. These define the scale-dependence of available runoff for spate irrigation, for the management of surface flows and of groundwater recharge.

A modelling framework to achieve this has been outlined, developed for a case study application to recharge dam yield evaluation in Northern Oman. By considering modelled response to multi-year spatial rainfall sequences (which could be based on observed rainfall or stochastically-generated rainfall), a risk-based assessment of sustainable resource yield can be carried out.

Such modelling is in its infancy and needs to be developed further. The stochastic modelling of spatial rainfall in arid areas has received little attention, and the method described above could be improved. However, recent work to develop spatial rainfall simulators for more humid climates (Chandler and Wheater, 2002, Yan et al., 2005) has led to tools that can also be linked to GCM and RCM scenarios of future climate, and hence evaluate response to climate change. Climate change issues are clearly important, and cannot now be neglected in developing plans for sustainable water resource management. Quantification of transmission losses is achieved using a simple model, with appropriate complexity for this purpose. However, controls on transmission losses are not well understood, and more work to quantify these experimentally is needed.

This paper has focussed on the quantification of sustainable yields from rainwater harvesting systems. It should be recognised that other aspects of sustainability are of equal importance for rainwater harvesting – ranging from technical issues such as the management of sediments in harvesting systems, to socio-economic issues such as the ability and incentives to maintain those systems. These issues are of course intimately related and ultimately the viability of such systems depends on the broad economic context defined by government for rural communities.

The above discussion has focussed on the management of water quantity. Clearly there is a broader set of issues related to water quality. For certain circumstances, enhanced recharge may be a means of improving groundwater water quality (for example in the remediation of saline intrusion) – alternatively, rising water tables could mobilise natural of anthropogenically-generated pollution. And where active management of groundwater is to be developed, water quality protection will remain important. The modelling framework could also be extended to incorporate issues of land management effects on runoff and recharge. There is concern in many arid and semi-arid areas that degradation of soils and vegetation has occurred. The use of rainwater harvesting techniques to regenerate rangeland areas is one such issue. Modelling systems for integrated catchment management are in their infancy in application to arid and semi-arid areas, but clearly have great potential for informing the development of integrated land and water management and policy.

References

Chandler, R.E. and Wheater, H.S. (2002) Analysis of rainfall variability using generalized linear models: A case study from the West of Ireland. Water Resour. Res., Vol 38, No 10, 1192, 10-1 – 10-11.

Goodrich, D.C., Lane, L.J., Shillito, R.M., Miller, S.N., Syed, K.H. and Woolhiser, D.A. (1997) Linearity of basin response as a function of scale in a semi-arid watershed. Water Resour. Res., 33,12, 2951-2965.

Jordan, P.R. (1977) Streamflow transmission losses in Western Kansas. Jul of Hydraulics Division, ASCE, 108, HY8, 905-919.

Lane, L.J., Diskin, M.H. and Renard, K.G. (1971) Input-output relationships for an ephemeral stream channel system. J.Hydrol. 13, pp.22-40.

Osborn, H.B., Renard, K.G. and Simanton, J.R., (1979) Dense networks to measure convective rainfalls in the Southwestern United States. Water Resour. Res.,15(6):1701-1711.

Wheater, H.S. (2006) Modelling hydrological processes in arid and semi-arid areas. In ‘Hydrological modeling in arid and semi-arid areas’, Eds. Wheater, H.S., Sorooshian, S., Sharma, K.D., Cambrideg University Press (in press).

Wheater, H.S., Butler, A.P., Stewart, E.J. & Hamilton, G.S. (1991a) A multivariate spatial-temporal model of rainfall in S.W. Saudi Arabia. I. Data characteristics and model formulation. J. Hydrol., 125, 175-199.

Wheater, H.S., Onof, C., Butler, A.P. and Hamilton, G.S., (1991b) A multivariate spatial-temporal model of rainfall in southwest Saudi Arabia. II Regional analysis and long-term performance. J. Hydrol., 125, 201-220.

Wheater, H.S., Jolley, T.J. and Peach, D. (1995) A water resources simulation model for groundwater recharge studies: an application to Wadi Ghulaji, Sultanate of Oman. In: Proc. Intnl. Conf. on Water Resources Management inArid Countries (Muscat), 502-510.

Yang, C., Chandler, R.E., Isham, V.S. and Wheater, H.S. (2005) Spatial-temporal rainfall simulation using generalized linear models. Water Resources Research, Vol. 41, W11415, doi 10.1029/2004 WR003739.

Water harvesting context in the Indian Subcontinent

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1 INTRODUCTION

Scarcity of water is one of the most pressing issues in the Indian subcontinent. Lives of millions of people in this region are adversely affected due to insufficient supply of water to meet their daily needs. Rising population, increasing urbanization and widespread pollution of water have also contributed to the problem of water availability. Management of water in the subcontinent has thus emerged as a major challenge of the 21st century.

The Indian subcontinent is a peninsular landmass of the Asian continent that covers about 10% of the Asian continent; however, it accounts for about 40% of Asia's population. The region is known as a subcontinent because its geography and geology are distinct from the rest of the continent. It is home to an astounding variety of geographical features, such as glaciers, rainforests, valleys, deserts, and grasslands that are typical of much larger continents. Geographically, the Indian subcontinent can be divided into the following regions: Himalayan states, Indo-Gangetic plain, Deccan Plateau, and Indian Ocean states. It includes India, Pakistan (excluding the Balochistan province), and Bangladesh, and other South Asian countries too i.e. Sri Lanka, Nepal, Bhutan and Maldives. The present paper explores the role of water harvesting in mitigating the water availability problems in four countries of the subcontinent namely India, Sri Lanka, Bangladesh and Nepal.

2. INDIA

India is a large country which supports about 1/6th of the world's population, 1/50th of the world's land and 1/25th of the world's water resources (Water Management Forum, 2003). Despite being endowed with mighty rivers like the Ganga, the Brahmaputra, the Krishna, and, the Godavari etc., the uneven distribution of rainfall across the country at different times of the year makes several parts of India fall under the water stressed, water scarcity and absolute water scarcity categories. Most of these water stressed and water scarce zones fall in the arid and semi-arid regions (refer Fig. 1) that are in general characterized by low annual rainfall and high evaporation. To combat the scarcity of water, water harvesting is being successfully implemented in many such arid and semi-arid areas of India that receive inadequate rainfall. The impact of water harvesting in the State of Rajasthan (western India) and various other water harvesting measures underway in several parts of the country are briefly described below.

2.1. Traditional Water Harvesting in Northeastern Rajasthan

Uptil the 1930s and 1940s, the Aravalli mountain range (one of the oldest in the world) in the State of Rajasthan had verdant forest cover. A multitude of traditional water-harvesting systems ensured that the low rainfall was optimally utilised to provide an adequate water supply throughout the year. However, due to mindless large-scale logging in later years, most of the rainwater got lost as surface runoff every year, resulting in considerable depletion of groundwater recharge. The complete transfer of water systems management from community to government created a cycle of neglect and scorn for time-tested traditions and a dependency-syndrome among the community. The synergy between humankind and nature that was the legacy of centuries of tradition was destroyed in a matter of decades. Drought became a recurring and grim reality in the region (Kishore, 2003).

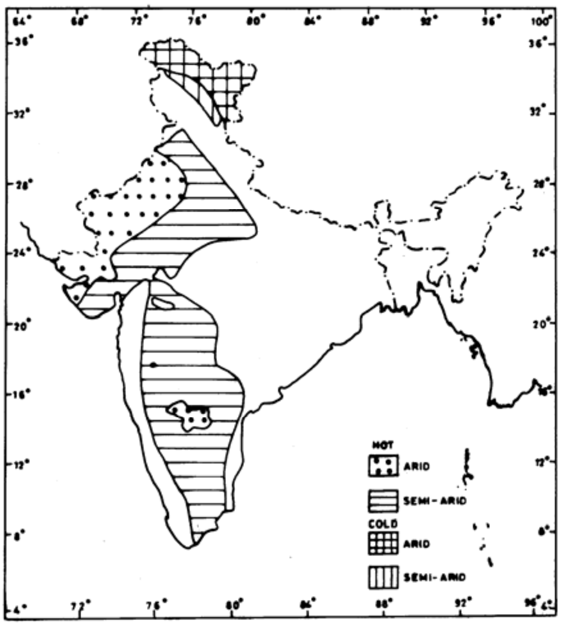

Fig. 1. Arid and semi-arid regions of India (Source: Maheshwari, 1989)

The Alwar district in the semi-arid zone of northeastern Rajasthan, one of the poorest in the State with rainfall measuring a meagre 620 mm was hard hit by one of the worst droughts in 1985-86. The water table receded below critical levels and rivers and wells dried up. Crop failure became common, the lack of vegetation led to soil degradation and monsoon run off caused soil erosion.

With help from Tarun Bharat Sangh (TBS), a grass root voluntary organization, the gritty villagers in one of the villages initiated work on reviving the traditional water harvesting systems of the area called *Johads*. These are earthen check dams that catch and conserve rainwater, leading to improved percolation and groundwater recharge. They are built across a slope to arrest rainwater; bound on three sides by the natural slopes of hills. The fourth side, a mud wall – usually semi-circular in form – holds back the monsoon run-off (Fig. 2). The height of the embankment varies from one *johad* to another, depending on the site, water flow, contours etc. In some cases, to ease the water pressure, a masonry structure is also added for the outlet of excess water. The water collected in a *johad* during the monsoon is directly used for irrigation, drinking, livestock and other domestic purposes. Another advantage of this structure is that it improves the moisture level at the sub-soil level in the fields. During winters when the *johad* is dry, it can be used for crop cultivation due to moisture present in the soil of the catchment area.

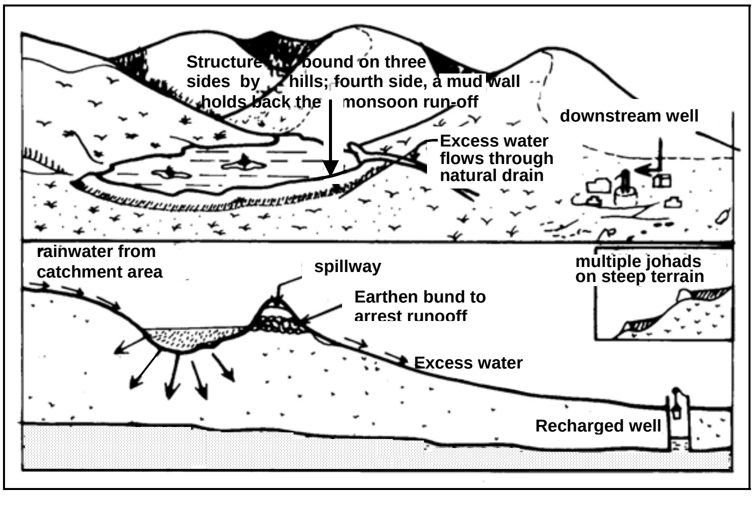

Fig 2. Rainwater harvesting using *johads* (adapted from Kishore, 2003)

Three years subsequent to the construction of *johads*, the rise in groundwater level several kilometers downstream of the rejuvenated structures was visible. The water harvesting work was soon taken up in 45 villages of the region, and quickly spread to still more villages. More than 5,000 johads were built and over 2,500 old structures rejuvenated by village communities in 1,058 villages in Rajasthan under the leadership of TBS. These water harvesting structures have provided irrigation water to an estimated 140,000 ha. Around 700,000 people in Alwar and neighbouring areas have benefited from improved access to water for household use, farm animals, and crops.

The revival of the system of *johads* has had a visible impact on the socio-economic scenario of the region. Aquifers have been recharged (Table 1 gives water levels in one of the villages) and water supply is now ensured for the entire year to meet the needs of both people and livestock. Livestock rearing being the lifeline of local communities, increased water and fodder availability has brought about an improvement in their economic status. Besides satisfying primary needs – drinking and domestic uses – it has increased food production, helped in conserving soil, increased biomass productivity, and even converted five seasonal rivers – the Arvari, Ruparel, Sarsa, Bhagani-Teldeh and Jahajwali Nadi – into perennials.

Besides other management measures such as inter-basin water transfer recycling and reuse of water for combating water scarcity, water harvesting has an important role in efficient utilization of rainwater for drought mitigation (as illustrated by the case study), raising the productivity of rainfed agriculture and nonarable lands, and providing easy access to water for communities in both urban and rural areas (Jain et al., 2004). Institutes like the Central Arid Zone Research Institute (CAZRI) located in Jodhpur (Rajasthan) have come up with improved design of different harvesting structures like the *tanka* (underground cistern) which is the most popular drinking water storage in western Rajasthan. About 12,000 *tankas* of CAZRI design have been constructed in western Rajasthan to store 475,000 m^3 of rainwater, which is sufficient for domestic use by 32,000 people throughout the year (Narain et al., 2000).

Table 1 Rise in groundwater level in Village Buja

No.	Total depth of well (m)	Depth of water level in 1985 before construction of *Johad* (m)	Depth of water level in 1994 after construction of *Johad* (m)
1	24.68	Dry	11.12
2	22.25	Dry	10.98
3	20.4	19.4	8.05
4	17.0	15.7 (mostly dry)	8.8
5	24.68	21.68	4.57
6	21.0	15.0	5.76
7	13.10	8.5	2.44
8	25.30	19.3	7.63
9	24.50	19.0	7.75
10	20.25	Dry	12.63

Source: AFPRO (1994)

Recognizing the significance of water harvesting in mitigating water availability problems, that are also attributed to increasing demands from a rapidly growing population and widespread pollution of water resources, the Govt. of India has launched several programs and campaigns to spread mass awareness and mobilize general population in managing water resources. *Hariyali* (meaning 'greenery') is a watershed management project, launched by the Central Government, which aims at enabling the rural population to conserve water for drinking, irrigation, fisheries and afforestation as well as generate employment opportunities through development of water harvesting structures such as low-cost farm ponds, nalia bunds, checkdams, percolation tanks and other groundwater recharge measures. The project is being executed by the Gram Panchayats (village governing bodies) with people's participation and the technical support is provided by the block (sub-district) administration. Another good example of water conservation efforts is the *Neeru-Meeru* (Water and You) program launched in May 2000 by the State Government of Andhra Pradesh. An additional storage space of more than 1800 million m^3 has been created in the state by constructing various water harvesting structures through people's participation. A water literacy drive '*Jalachaitanyam*' (water awareness) has created large-scale awareness about conservation measures and sustainable management of water resources amongst the people of the state. In states like Tamil Nadu in South India, rainwater harvesting has been made mandatory for all the buildings, both public and private. In New Delhi, the capital of India, rainwater harvesting is a compulsory feature in all new buildings with a roof area of more than 100 m^2 and in all plots under development with an area of more than 1000 m^2.

The economy of the country is currently witnessing rapid growth. To sustain the economic development, proper management of water resources is of paramount importance. Harvesting the rainwater through suitable schemes holds the key to solving many of the water related problems in India.

3. SRI LANKA

Sri Lanka is endowed with approximately 4500 km of rivers, 2400 km of irrigation canals and 3500 deep-water tanks, reservoirs, and artificial and natural wetlands. The mountains and the southwestern part of the country, known as the 'wet zone', receive ample rainfall (an annual average of 250 cm). Most of the southeast, east, and northern parts of the country comprise the dry zone (Fig. 3), which receives between 1200 and 1900 mm of rain annually. Much of the rain in these areas falls from October to January; during the rest of the year there is very little precipitation. The arid northwest and southeast coasts receive the least amount of rain, 600 to 1200 mm per year, concentrated within the short period of the winter monsoon.

Besides using groundwater from dug wells, the rural population in the dry zone utilizes irrigation reservoirs and canal water for domestic use, especially in the dry season when groundwater sources are depleted due to increased demand. Often the reservoir waters are not fit for human consumption due to contamination in extremely dry conditions. Cattle and humans frequently meet their water needs from the same source. This situation prevails in most parts of the North Central, North Western and the drier parts of the Southern Province.

At present, only 60% of the rural population has access to safe drinking water. This leaves a significant population in rural Sri Lanka where none of the conventional water supply sources can provide water due to financial and/or technical constraints. Rainwater harvesting is one of the most viable options for these communities. Traditionally, in Sri Lanka, rainwater is collected from trees, using banana leaves or stems as temporary gutters; up to 200 litres may be collected from a large tree in a single storm. While different types of traditional rainwater harvesting have been in use, roof-water harvesting appears to be the most effective in terms of quantity and adequacy. Many individuals and groups have taken the initiative and developed a wide variety of water harvesting systems.

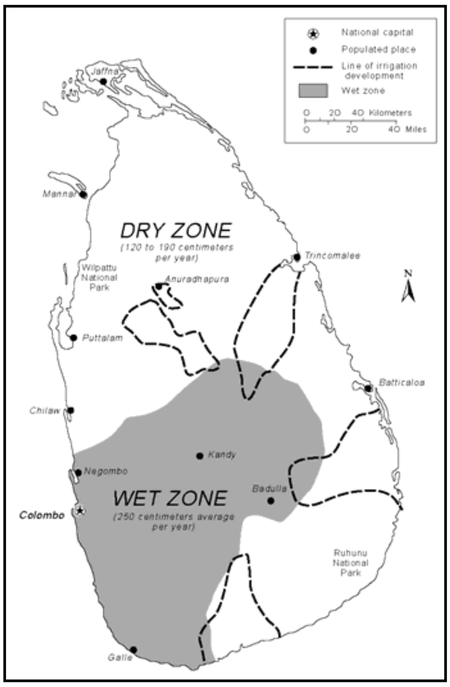

Fig 3. Wet and dry zones in Sri Lanka (Source: Anonymous, 2006)

3.1 Impact of Rainwater Use in Dematawelihinna Village, Badulla District

Most of the traditional rainwater harvesting in Dematawelihinna village was initially limited to small quantities collected in household utensils. To meet the water supply requirements, rainwater harvesting from roof catchments was considered to be the only feasible option by the governmental and non-governmental organisations working in the area. Initially, the majority of villagers rejected rainwater harvesting technology due to health reasons. Later on many of the villagers consented and subsequently 146 rainwater tanks were constructed in the village. These 5000 liter rainwater tanks were designed to supply 20 liters per person for a family of five for a 50-day dry period. However, water stored in these tanks has been used by the villagers throughout the year due to intermittent rain received in the wet season. During the dry season, which usually lasts for four or five months, the water-use pattern changes as families fetch more spring water and try to maintain the rainwater storage as a security. Some of the villagers located away from natural springs or dug wells use only rainwater for all domestic needs.

The most significant impact of rainwater harvesting in the community has been on its social life. Previously, people in water-scarce areas had to restrict their social life due to the pre-occupation with fetching the daily quota of water. With the introduction of 5000 liter tanks, the users could entertain friend and relations, and attend career development programmes. In Dematawelihinna, school teachers had previously complained of poor school attendance and frequent failure to complete homework, attributed to the children fetching water in the night. This problem has been totally eliminated since the introduction of rainwater tanks. Though water-borne diseases are a common occurrence among users of polluted water, the lack of water-related diseases in the village indicates that the collected water is fit for drinking after boiling.

To make use of the plentiful rain of the wet season, tanks can be built on a domestic scale that can store about 10,000 litres of rainwater at a time, which is sufficient to irrigate a quarter or half an acre of land and successfully grow low water-intensive perennial crops. However, in Sri Lanka, the water supply infrastructure has not kept pace with growing needs and rainwater harvesting has not been promoted as in India. Institutions like the Lanka Rain Water Harvesting Forum, which carries out research on development of low cost storage techniques, have been propagating rainwater harvesting in this country. Only about 14,000 rainwater harvesting systems function in the country (Moonesinghe, 2004). In rural areas where communities often struggle to gain access to clean water without having to travel miles everyday, a lot of scope exists for expansion of rainwater harvesting systems.

4. BANGLADESH

Bangladesh is faced with numerous water-related problems: flooding, droughts, arsenic contamination of groundwater, surface water pollution by point sources and non-point sources. The water supply in Bangladesh is primarily based on groundwater with about 103 million people depending on shallow tubewells for water supply. An estimated 29 million people who are exposed to arsenic contamination through contaminated shallow tubewells and few production wells in urban centers, require alternative water supply (Ahmed, 2002).

The sources of water available in Bangladesh for development of alternative water supplies are groundwater, surface water and rainwater. The amount of rainfall varies both spatially and temporally, and is mainly restricted during the months from April to September. While the maximum amount of average annual rainfall occurs in the northeastern districts of Sylhet and Moulivibazar, the minimum amount falls in the western/southwestern districts. Groundwater contamination by arsenic is more severe in the western/southwestern districts, where rainwater harvesting can be suitably used to solve the polluted drinking water problems. However, most buildings in Bangladesh are not designed for rainwater harvesting. Structural modification of buildings/ houses in urban areas as well as houses in rural areas will be necessary to make them suitable for rainwater harvesting (Khalequzzaman, 2005). Although rainwater harvesting will not be able to replace all other sources of drinking water, it will certainly be able to ease the pressure on surface water and contaminated groundwater usage as the primary source of drinking water. In recent years, rainwater harvesting technique has been implemented in Sylhet district of Bangladesh. Rainwater harvesting plants set up in different parts of the district have ensured arsenic free water for a large number of people of the district, particularly in rural areas. The stored rainwater has been used by the villagers round the year for various purposes including drinking.

Although, Bangladesh Water Development Board Act 2000, mentions undertaking of activities related to harvesting of rainwater for irrigation, environmental preservation and supply of drinking water (BWDB, 2000), the technology is yet to become popular in Bangladesh. The development of a rainwater harvesting plan that is economically and technically feasible for meeting the drinking and irrigation water requitrements, needs to be considered in the integrated water resources management plan of the country.

5. NEPAL

Nepal is a landlocked country with the highest peak in the world. About 77% of the area is mountainous with three distinct climatic and altitudinal zones as follows: (1) the inner Terai (300 - 1000 m) which is a stretch of very fertile flatlands, (2) the mid hills (1000 - 4000m), and (3) the mountainous areas (> 4000 m) including the Himalayas. The topographic orientation as well as vertical extension of this country creates diverse spatial and temporal variations in rainfall. The average annual rainfall of Nepal is approximately 1700 mm. The problem in the hills and mountains is that excessive rain in monsoon season causes catastrophic soil erosions whereas water scarcity is faced in non-monsoon periods. The water scarcity problem is acute for communities dwelling in the mountains/hilltops (Shrestha, 2001).

Although nature has bestowed Nepal with ample water resources, the percentage of people with access to safe water in rural Nepal is only 43%. Gravity flow schemes operate in the hill areas and hand pumps are installed in the inner Terai under several projects supported by non-governmental organisations. Equipped with increasing support from international agencies, the non-governmental organizations are aiding harvesting of water for domestic use as well as for irrigation.

For community settlements on ridges and crests, rainwater harvesting is a viable technological option. Organisations like Nepal Water for Health are engaged in trying out various options for rainwater harvesting to suit different locations and conditions. At domestic level, ferro-cement tanks of 2000 liters capacity have been utilized while specially designed ferro-cement tanks of 24000 liters capacity are being used to store water for schools and institutional buildings.

For remote villages in Nepal, fog water collection technology can provide improved access to potable water (NEWAH, 2006). The technology to collect water from fog consists of erecting a plastic woven mesh vertically in the path of moving fog. In Nepal the best conditions for this occur on hill or ridge tops from 2000 to 3500 m above sea level. The tiny fog water droplets coalesce on the mesh and drip down into a collection system. Three such fog water collection projects have been implemented in Kalpokhari, Megma and Dandabazar in Eastern Development Region of Nepal. Apart from these, attempts are also being made with the help of village communities for the rehabilitation of old ponds and indigenous spouts of Kathmandu valley.

6. CONCLUSIONS

The escalating scarcity of water, varying in scale and intensity at different times of the year, in different regions of the subcontinent is a cause for serious concern. This alarming situation is a result of natural factors as well as human activities. Adoption of suitable water harvesting schemes can go a long way in solving many of the water availability problems. Numerous water harvesting techniques, ranging from traditional to modern, exist for both drinking water supply and irrigation purposes in the arid plains, the semi-arid plains, the floodplains and in the hilly/mountainous regions of the subcontinent. A significant percentage of the subcontinent's population is engaged in farming practices. A better understanding of the viability of various water harvesting schemes under different agro-ecological and socio-economic settings would lead to improvisation of farming systems in the subcontinent. Also, little is known about socio-economic, environmental and hydrological impact of upscaling small-scale water harvesting techniques. With increasing adoption of such techniques, it will be useful to have prior knowledge on consequences of upscaling at catchment and river basin scale.

References

AFPRO (1994) Survey conducted by AFPRO (Agriculture for Food Production) in Village Buja, Alwar District, Rajasthan. Data published in Ecologist Asia, Vol. 11, No. 3, July-September 2003.

Ahmed, M.F. (2002) Alternative water supply options for arsenic affected areas of Bangladesh. Int. Workshop on Arsenic Mitigation in Bangladesh, Dhaka, 14-16 January, 2002.

Anonymous (2006) Irrigation and precipitation map of Sri Lanka, downloaded in 2006 from lcweb2.loc.gov/frd/cs/sri_lanka/lk02_01b.pdf

BWDB (2000) The Bangladesh Water Development Board Act 2000.Act No. XXVI of 2000.

Jain, Sharad K., Anupma Sharma and Rakesh Kumar (2004) Freshwater and its management in India. Int. J. River Basin Management, Vol. 2, No. 4, 259-270.

Khalequzzaman, M. (2005) Can rainwater harvesting be a solution to drinking water problem in Bangladesh? Short Note, Georgia Southwestern State University, downloaded from www.eb2000.org/short_note_4.htm

Kishore, A. (2003) Taking control of their lives. Ecologist Asia, Vol. 11, No. 3, July-September 2003.

Maheshwari, J. K. (1989) Processing and utilization of perennial vegetation in the arid zone of India. In: Role of Forestry in Combatting Desertification, FAO Conservation Guide 21, Rome, 137-172.

Moonesinghe, V. (2004) Rain Water Harvesting Technologies in Sri Lanka, SARID archives, January 2004, downloaded from www.sarid.net/archives/sarid-archives.htm

Narain, P., K.D. Sharma, A.S. Rao, D.V. Singh, B.K. Mathur and Usha Rani Ahuja (2000) Strategy to Combat Drought and Famine in the Indian Arid Zone, Central Arid Zone Research Institute, Jodhpur.

NEWAH (2006) Fog water collection. Rain water harvesting by Nepal Water for Health (NEWAH) downloaded in 2006 from www.newah.org.np/water.htm

Shrestha, G. (2001) Water harvesting as an appropriate technology: The global and local perspective. BS Thesis, Kathmandu University, Nepal.

Water Management Forum (2003). Inter-basin transfer of water in India – prospects and problems.Water Management Forum. The Institution of Engineers (India), New Delhi.

An Integrated Approach towards Assessing the Feasibility of Domestic Rainwater Harvesting in Malta

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Abstract

History gives testimony that traditional rainwater harvesting (RWH) was once considered by several societies to be the solution to water supply problems worldwide. Yet it has long been cast off as supposedly better alternative technologies were discovered. This paper explores the potential of small-scale domestic rainwater harvesting on the island of Malta by taking an integrated look at the physical, social, and economic environments. It explores the extent to which domestic rainwater harvesting has been forgotten despite the fact of it being embedded within Malta's history for centuries. The study closely examines the cost-effectiveness of this technology both at a local and national scale and teases out the hurdles that have brought about its rejection by means of residential and water professional interviews.

The main findings indicate that island characteristics of smallness, contested land, and lack of proper planning and enforcement have instigated the decline in use of llirainwater cisterns. A low shadow price of water, despite public perception that government water tariffs are high; and a high financial cost of cistern construction have further limited the potential of its development. Also small-scale rainwater harvesting does not have the glamour or high political profile large scale projects do and so does not attract the required attention in order for it to be encouraged nationally. Proper planning, enforcement, education and regulation, as well as policy integration, seem key to unlocking the reluctance of RWH use.

1. INTRODUCTION

Rain is the earth's primary source of freshwater and therefore it is of no surprise that societies in all parts of the world have harvested rainwater since prehistory for agricultural and domestic use (Smet and Moriarty, 2001). Its widespread use, however, has fluctuated in the past reaching a decline when there was a shift in favour of more centralised engineering approaches to water supply. This decline in rainwater use occurred at the expense of surface and groundwater supplies, which in some areas have reached a critical stage in terms of quantity and quality. Coupled with growing demand, these threats have caused a growing shift from the paradigm of supply to that of demand management; to the extent that different technologies have been evolved and are still being appraised to this day (Tate, 2000). These include increased efficiency in seawater and brackish water desalination (Pearce, 2006), the reuse of greywater and sewage water (Jeffrey *et al*., 2000) as well as domestic RWH and interception of rainfall to augment ground or surface water supply, termed managed aquifer recharge (Gale and Dillon, 2005).

In considering the alternatives to augment supply and manage demand, it is vital to examine not only the technical solutions and their physical feasibility but also the socio-economic issues such as willingness and ability to pay, public perceptions, risk analysis, the assessment of monetary and non-monetary benefits and environmental impacts. In order to declare a technological solution to be cost-effective it is essential that it valorises the social and environmental value of water; it enhances the region's water resource availability and maximizes environmental benefits. RWH will be looked at in relation to the above highlighted issues, as one of the alternative solutions in augmenting water supply in the Maltese Islands.

1.1 The water resources of the Maltese Islands

The Maltese Islands are located 35`50N and 14`35E in the centre of the Mediterranean Sea (Figure 1). The archipelago comprises a total area of 316 km^2 and has a population of just over 404,000 inhabitants (NSO, 2006), making it one of the most densely populated countries in the world (UN, 2005). With a total average precipitation of 530mm per annum Malta has a water availability of 40m^3/capita per year and thus is amongst the lowest in the world (Angelakis, 2004).

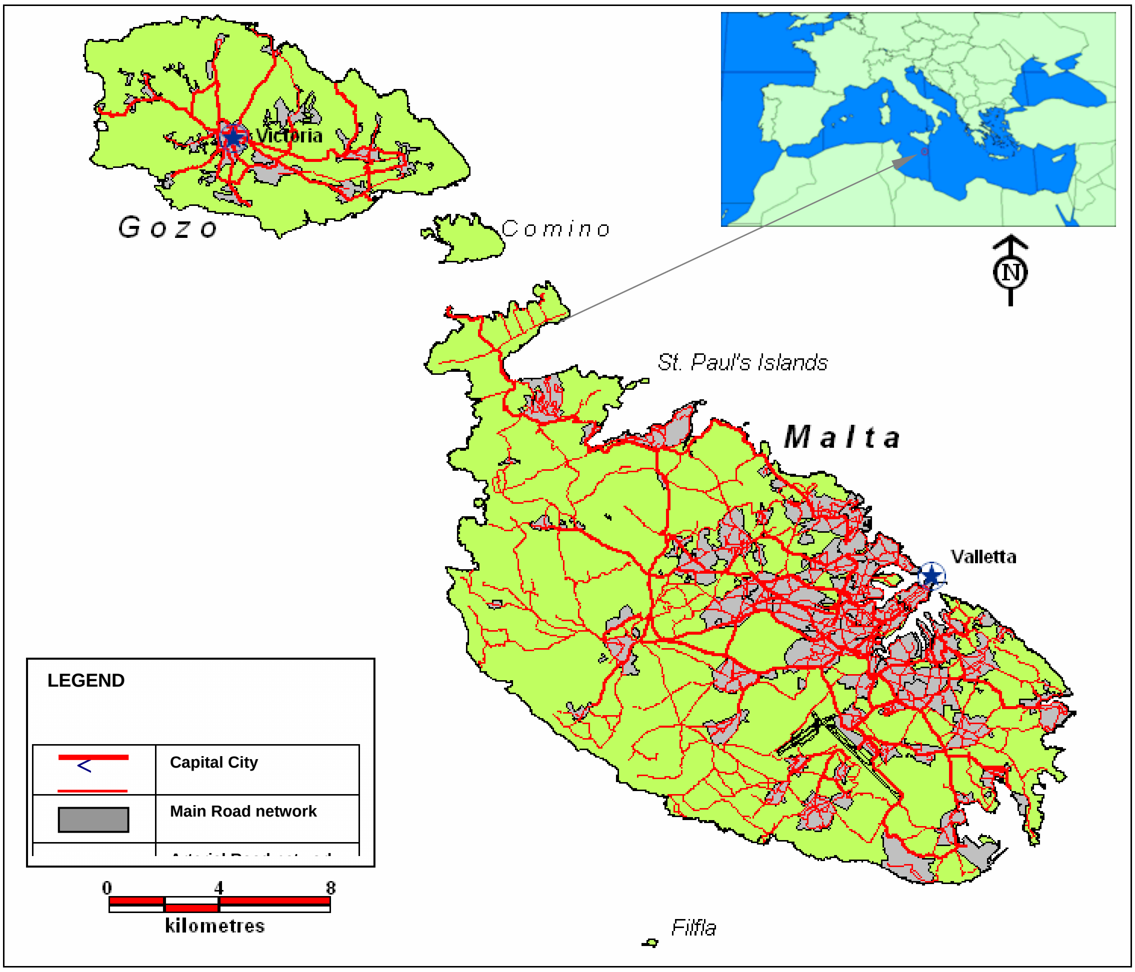
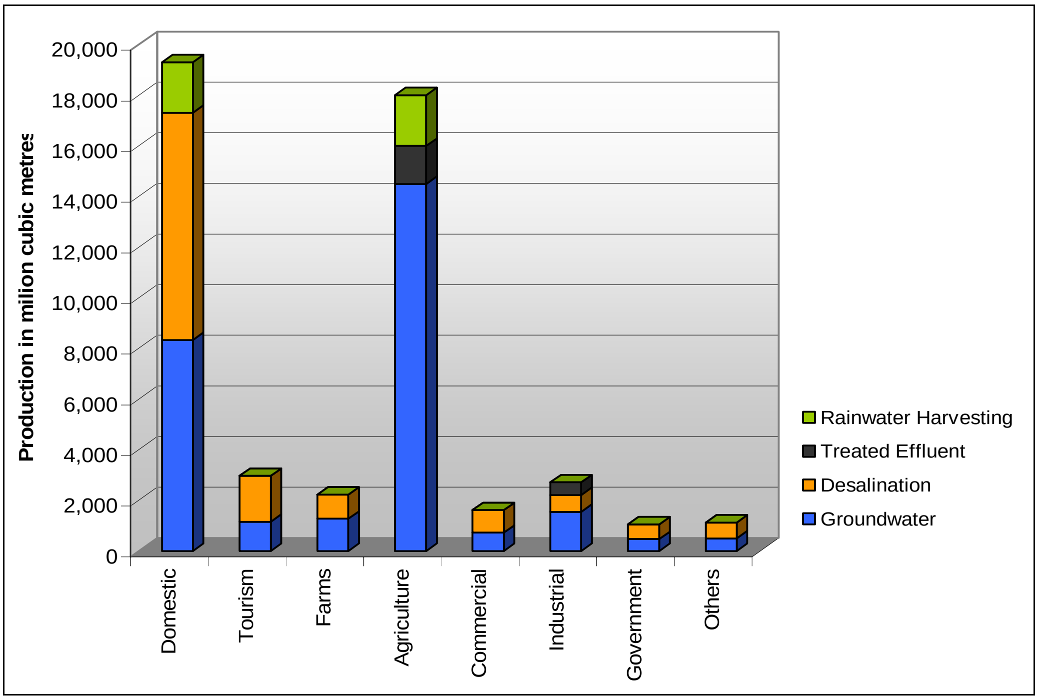


Figure 1 A map of the Maltese Islands showing extent of built up area and road network.

The archipelago is deficient in surface water bodies. Rainwater, the sole natural source of freshwater on the islands recharges the two main aquifers: the mean sea-level and perched aquifers. However with the increasing deterioration of groundwater quality and an increasing need to produce high quality water due to the Drinking Water Directive (98/83/EC), costly Reverse Osmosis (RO) desalination is gradually taking over groundwater production. In 2005 the WSC produced 54.3% of total water consumed by RO plants and 45.7% by groundwater abstraction (WSC, 2005). RWH and unconventional sources only account for 7% and 3% of total water production respectively (Figure 2).

The socio-economic costs of a lack of water sources is already bearing on the domestic, industrial, agriculture and tourism sectors of the economy. A larger volume of water will have to be produced mechanically by Reverse Osmosis. This raises the dependency on oil imports and induces a subsequent rise in electricity costs. Simultaneously climate change is also exerting its influence. Sea-level rise will render groundwater unfit for consumption due to the ingress of sea water within the Ghyben-Herzberg freshwater lens. In view of this RWH would be a means of obtaining a secure freshwater supply and should not be marginalised but assessed in relation to other sources of supply.



As indicated by MRA data the domestic sector is the largest water consumer in the Maltese Islands with a total of over 18.000 million m^3 *being consumed in* ***2003*** *(MRA, 2005) (39%). Arable agriculture consumes a further 37%.*

Figure 2 ***Estimates of sectoral water consumption by source (2003)***

Source: MRA 2005 data

1.2 Aim and Objectives

The principal aim was to assess the potential of RWH for domestic use in Malta. In order for this aim to be tackled holistically the following key factors for the successful development of rainwater harvesting at a local and national scale were identified.

Physical feasibility (suitability of the climate). Extensive dry periods may limit the effectiveness of a RWH system. This however depends on the purpose of use of the rainwater collected. Unlike less economically developed societies, where rainwater is often the only source of water used for drinking and cleaning purposes; more developed countries can restrict rainwater use to second class purposes because of their ability to pay for alternative sources of supply which demand less effort in terms of Operation & Maintenace (Po *et al*., 2003).

A conducive social environment at residential level whereby there is no cultural resistance to the use of RWH (Corral-Verdugo *et al*., 2002). There should be a genuine demand for the product whereby, the public is made aware of the economic benefits of additional 'productive' water.

An effective economic environment which permits access to initial start-up funds or government incentives particularly in social deprived groups of people also an **enabling socio-economic environment** whereby key planning and technical skills are present at all levels of society, particularly in implementing authorities and Non Governmental Organisations.

An enabling political and legislative environment that supports RWH and includes it as a key option within various development planning and water policy tools as a supply augmentation approach to an increase in water demand.

2. METHODOLOGY

The integrated approach is based on the three feasibility studies: physical, social and economical and involves a triangulation technique that draws on observations, the collection of secondary data and interviews. The balance of all three feasibility studies and the basis of the different data sets collected for each were founded on the systematic integrated model depicted in Figure 3 to produce a holistic study of RWH in its socio-environmental, socio-cultural and socio-economic sphere

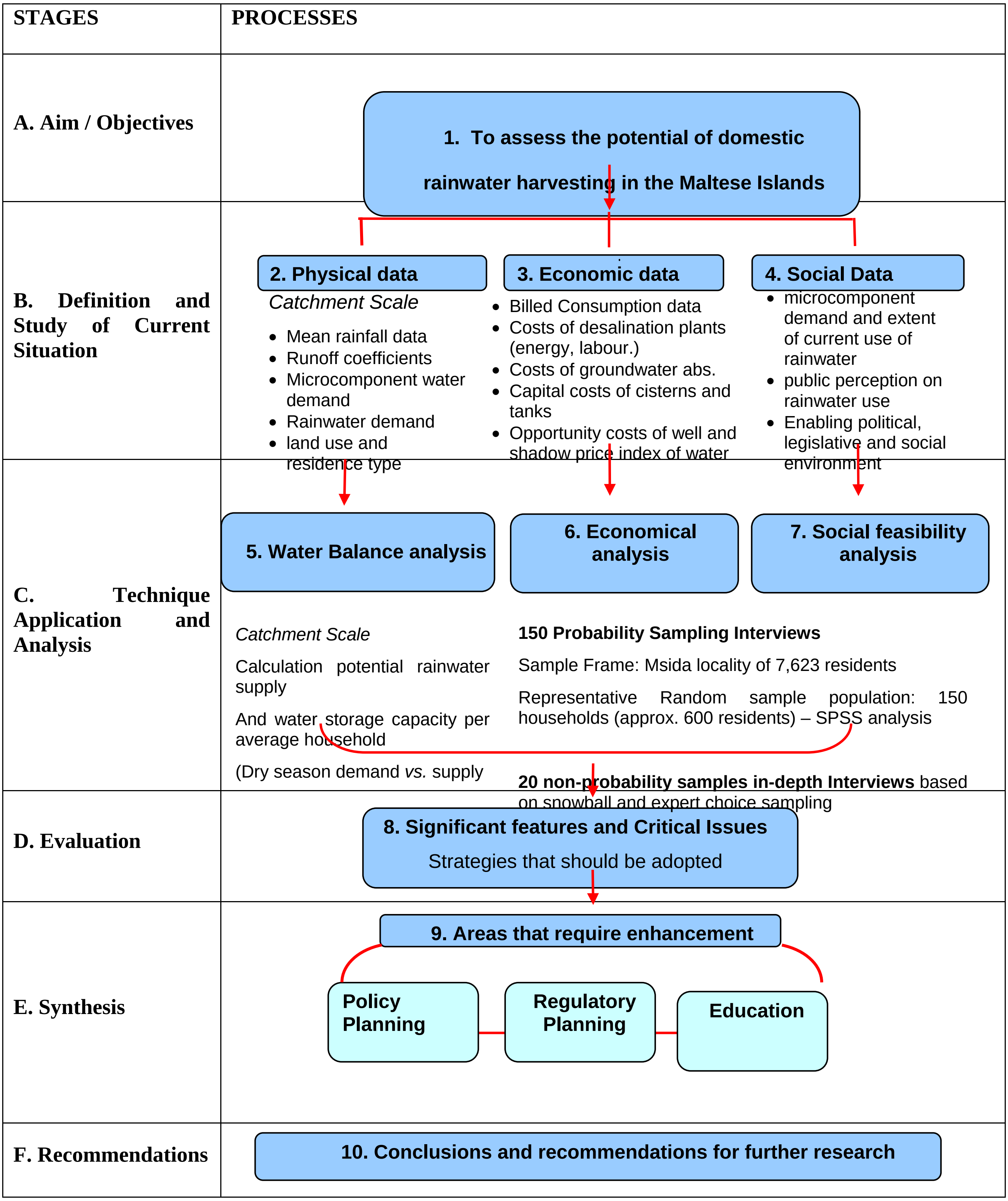


Figure 3 The Integrated model approach developed for the assessment of the potential of rainwater harvesting in Malta.Physical Analysis: Observation and secondary data sources

In order to establish the physical feasibility and facilitate the calculation of the optimal size of storage for rainwater, three components of demand and supply had to be addressed. These were:

1. The microcomponent demand of water as a resource and the actual demand of rainwater in the average household.
2. The potential rainwater supply considering rainfall distribution and its spatial and temporal variations.
3. The seasonal balance of the potential rainwater supply that can be harvested, together with demand, depending on climate and water use in the average household

Social and Economic Analysis: Household Interviews and Cost-Benefit Analysis

The interviews carried out at the domestic level were central to the findings of the social and economic feasibility analysis since the results had to reflect:

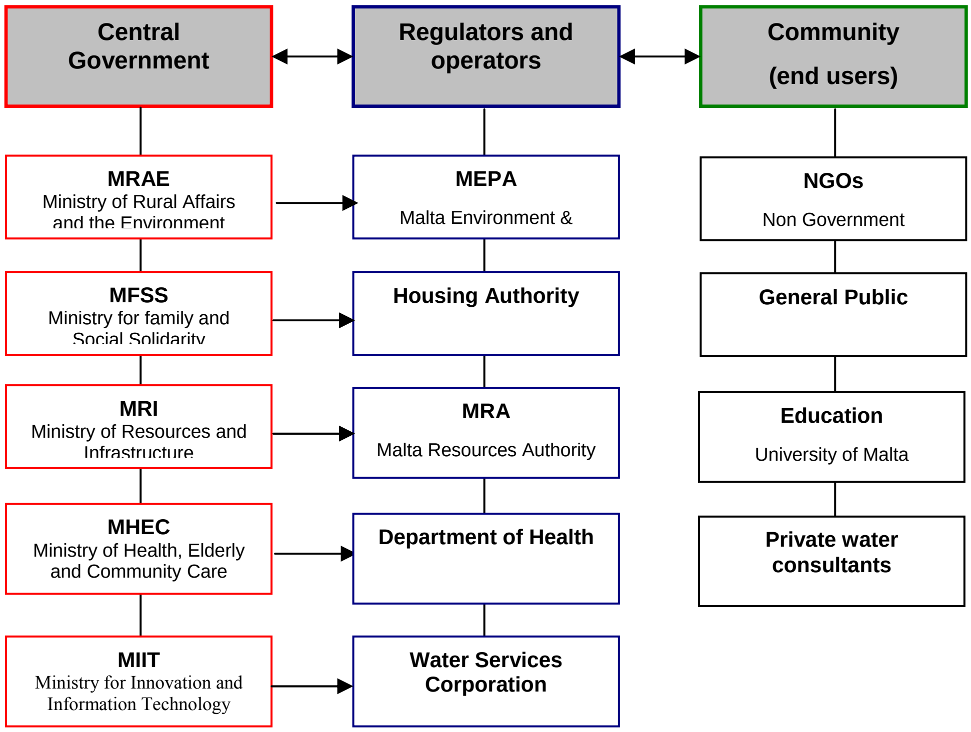


Figure 4 Stakeholder map used to identify key statutory bodies and beneficiaries from rainwater harvesting implementation.

(i) The socio-economic structure of the average Maltese household and their ability to pay for water utility services and rainwater cisterns.

(ii) The microcomponent demand of water use at the domestic level and the degree to which the public is aware of how much water it consumes for different purposes in the home.

(iii) Public perception regarding current water prices and their conservation attitudes in saving or recycling water.

(iv) Whether there exists a significant seasonal difference in water demand in an average household and its implications for RWH.

(v) Public perception regarding RWH; the present extent of its collection and use at the domestic level and perceived obstacles that have hindered its use.

(vi) Whether there is any genuine demand for RWH at the public level by revealing their willingness to pay for a cistern and the respective opportunity cost of water as a resource.

The physical rainwater harvesting potential of the Maltese Islands

Precipitation patterns in the Maltese Islands

The primary task in the design of a RWH system is the balancing of the differing rates of water supply and demand. Supply is determined by the maximum yield of rainwater from any catchment. This in turn is dependent upon 2 variables: the total rainfall and size of the catchment. As Stuart (2001) points out, the total yield is subject to the runoff coefficient and storage capacity of the harvesting system created.

Water availability was calculated by studying climatic data. 21 years (1985-2005) of rainfall data were collated and the calculated monthly averages are depicted in Figure 5 to show the yearly distribution of rainfall.

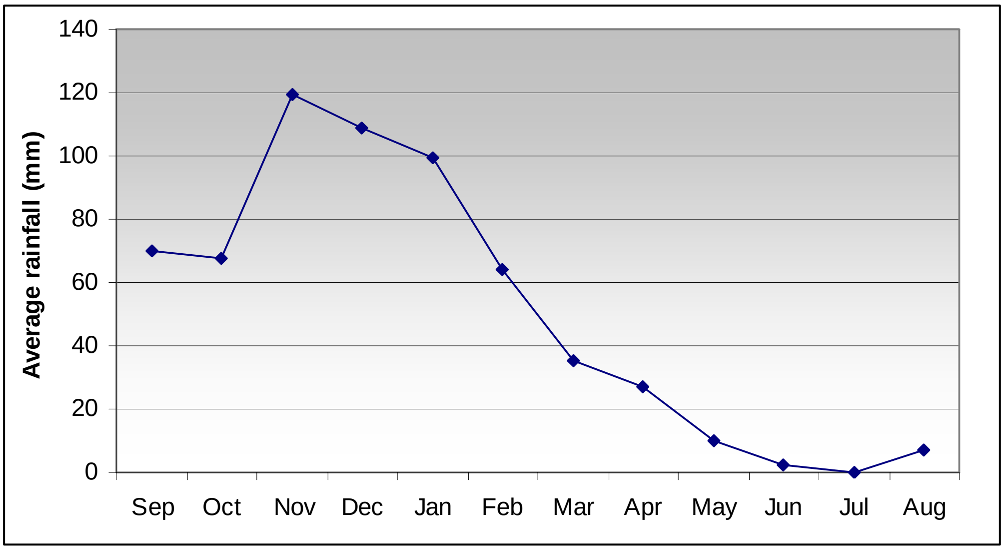


Figure 5 ***Twenty year (1985-2005) mean monthly rainfall for the Maltese Islands.***

Mean number of days with rain (1985-2005)											
SEP	**OCT**	**NOV**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**
5	8	13	15	14	11	8	6	3	1	0	1

Table 1 ***Mean number of days with rain for the years 1985 – 2005***

Additionally, the Mediterranean type of climate delineates a biseasonal climate. Shortage of water supply in summer is exacerbated due to high average temperatures that vary between 25ºC to 37ºC (MaltaWeather.com). The water shortage is best demonstrated by the temperature-rainfall graph as shown in figure 6.

The regional distribution of rainfall throughout the islands is more or less equal. Microclimate variations may exist, however, but no data are available for the present study therefore homogeneous distribution was assumed and the national rainfall average was utilised for that of the Msida catchment.

Rainfall is poorly distributed throughout the year reaching a maximum during November, December and January. Significant flash floods occur in the September-October period as shown by the average number of rain days in Table 4.1; whilst rainfall in successive months is more equally distributed. The dry summer months, June-August, coincide with the peak of water demand due to a domestic rise in water consumption, and the arrival of the height of the tourist season. This reveals the importance of a large containment volume required to store winter runoff for summer use

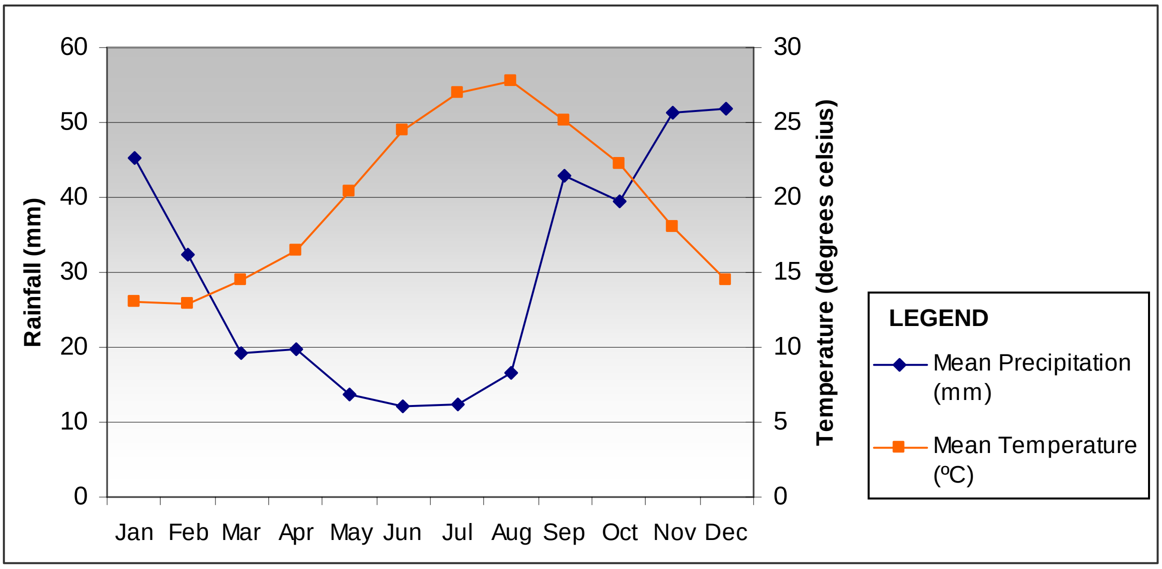


Figure 6 Water supply shortage is acute in the summer months.

The regional distribution of rainfall throughout the islands is more or less equal. Microclimate variations may exist, however, but no data are available for the present study therefore homogeneous distribution was assumed and the national rainfall average was utilised for that of the Msida catchment.

DEMAND: PER CAPITA WATER CONSUMPTION

Exploring domestic demand and the attempt to forecast it is one of the drivers behind investment into water resource schemes including that of RWH. Total water produced by the WSC reached its lowest level in 2005, since its inception in 1992, standing at 31 million m^3 (WSC, 2005). In 1997 consumption stood at 78 l/capita/day (NSO, 2002). After the 1997 price hike in water tariffs, consumption dropped to 63 l/capita/day. By 2000 it increased to 70 l/capita/day[3] (NSO, 2002).

In a recent economic survey (MRA, 2004), domestic **price elasticity** of water demand in the short run was estimated to be -0.28 and -0.37 in the long run. The higher value indicates that only after a certain time lag do households respond to price changes and thus tariffs do have a delayed but significant effect on per capita consumption. Therefore water consumption patterns are expected to fluctuate with the rise and fall of water tariffs. Even so water demand remains relatively inelastic since it is considered a necessity.

Price is only one of several factors that influence per capita consumption. Others include household size, housing type, socio-economic groupings and even the rateable value of properties (Gardiner and Herrington, 1986). According to Edwards and Martin (1995) the relationship between **household size** and per capita consumption is inversely related. In the Msida case, this was tested using two variables from the RI data: the water billed rate reflecting billed consumption; and household size. Section A of the RI asked residents to indicate their water bill amount as an indicator of water consumption. What complicated the task was the inclusion of the subsidized rates in water bills and so each individual water bill had to be reviewed in light of these subsidized values. Table 2 shows how water rates are estimated for Maltese households.

[3] Figure includes the tourist population. According to MTA (2000) tourists consume up to 1.5 times more water than locals do.

A Spearman's Rank Correlation Coefficient test could then be applied to assess whether a similar inverse relationship between household size and consumption existed. When considering this in the context of RWH use, this would mean that restricted cistern size would indirectly encourage water conservation in smaller households since harvested rainwater would have to be rationed throughout the year. Contrary to what Edwards and Martin (1995) claim for the UK, family size and consumption in Malta are directly proportionate. A significant positive correlation was found (table 3).

Table 2: Water Service Corporation water rates for the year 2006

Domestic	
Service charge per year	**Lm 12**
Cubic metres per person per year	
$33m^3$	**Lm0.16,5**
Exceeding $33m^3$	**Lm1.10**
Rebate/person > 4	Nil
Meter rent	**Lm 12**

Correlations

			MEMBERS	W_BILL
Spearman's rho	MEMBERS	Correlation Coefficient	1.000	.350**
		Sig. (2-tailed)	.	.000
		N	110	98
	W_BILL	Correlation Coefficient	.350**	1.000
		Sig. (2-tailed)	.000	.
		N	98	98

**. Correlation is significant at the .01 level (2-tailed).

Table 3: A statistically significant relationship between household size and water consumption.

This divergent result might be due to the fact that families are extremely aware of their outlay on water; explaining why water pricing has always been a sensitive political and social issue on the Islands. 59.1 % of the sample population stated that water rates are too high despite the fact that the government offers subsidized rates. A general observation was that the price of water is perceived to be high due to the expense of fuel. 67% mentioned this point. A positive international trend in fuel prices and Malta's continued reliance on RO production would aggravate this. A shift in favour of renewable energies would lessen this dependency on fuel (Energy Policy, 2006) and makes a valid case for the integration of energy and water policies.

Enemalta and WSC incorporate the water and electricity charges on one invoice and so customers pay a combined water and electricity tariff. It was observed that when residents were asked to indicate their water bill, the joint electricity and water charge was given. On examining the water rate, 47% of occupants who originally thought the rate to be expensive found it reasonable. This indicates that a combined electricity-water bill influences perception. In this analysis their first impression prior to examining the bill was used.

The relationship between **socio-economic groupings** and per capita consumption was tested using income bands and water bill consumption rates from the residential interviews (RI) data. The relationship (figure 8) indicated that there is a statistically insignificant association (chi-squared p-value of 0.447) between income bracket and water consumption in the Msida area probably due to the prevailing perception that water is expensive.

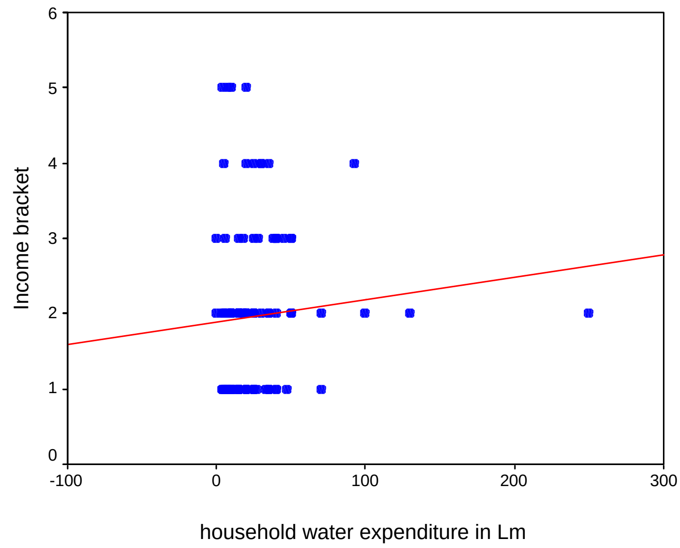


Figure 8: A statistically insignificant relationship between average household income and water expenditure in the Msida area.

Average yearly income household bracket:

1 – less than Lm 6,000

2 – between Lm 6,000 and Lm 10,000

3 – more than Lm10,000

4 – no comment

The microcomponent water demand of the average Maltese household.

The domestic microcomponent demand for water was analysed by means of the RI and its findings reflect some lifestyle patterns in demand.

The RI also attempted to classify the consumption of water in the household depending on purpose of use. The classification of water consumption depended significantly on the respondents' perception of water use in the home and could not be verified through the use of scientific data loggers or real-time equipment. This was the major drawback of the analysis. Nevertheless the claimed rates of water bills paid were matched with the suggested water consumption rates for each use. Also questions regarding bathing frequency and duration, laundry frequency and amount of loads per day and per week were asked and correlated with the respondents' perceptions of water consumption for each corresponding use. This enabled a derivation of a hypothetical or perceived average percentage of consumption for each component rather than an actual figure. Although the final results are not an accurate account, the perceived microcomponent demand allows one to see that the immediate three main household components that consume most water are laundry, bathing and toilet flushing (Figure 9).

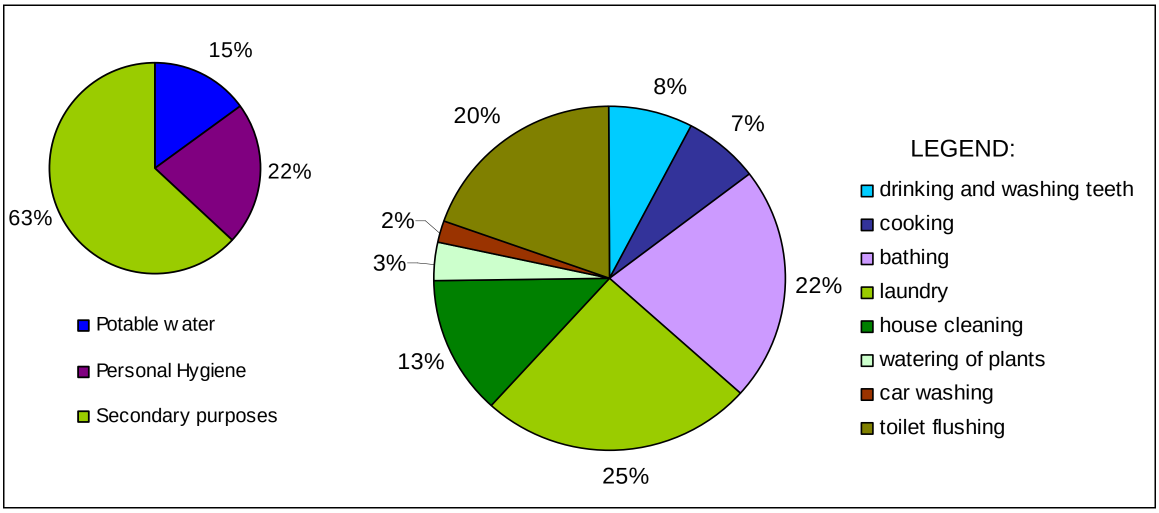


Figure 9: The perceived average microcomponent demand of water in Msida.

Secondary class purposes do take up most of the water consumed in the home meaning that only 37% of highly treated water is utilised for its intended purposes. 63% of it is lost to uses that don't require high quality water. Economically, resource wise and environmentally this is a waste and does not make sense in a resource deprived country like Malta.

The seasonal variations in demand

Summer and winter variations in water demand at home were not studied in detail. However, the RI helped to expose which microcomponents differ in consumption between seasons; bathing and gardening.

i. Bathing

58 % of households bathe more frequently in summer, denoting an average difference of up to 15 litres/capita/day. A chi-square test investigated the hypothesis that average summer bathing frequency, and therefore water demand, is higher than in winter. A positive relationship resulted.The average showering duration was also assessed.

Shower duration	Frequency	Percent	equivalence in litres
< 10 minutes	70	63.6	50-80 l
10-20 minutes	37	33.6	80-150 l
20-30 minutes	3	2.7	150-200 l

Table 4: Average household shower duration in minutes and equivalent litres consumed.

On scrutiny, the age group that lets the water run the longest is the 15-24 year olds. Two reasons explain this misuse; educational failure and no responsibility for bills. This draws attention to the importance of educational campaigns which should target children at a young age.

(ii) Gardening

Very few urban houses in Malta, including Msida, have large gardens. Plants are grown in yards or on roofs, and thus, the watering of plants in an average home does not consume considerable quantities of water. An estimated 4-8 litre difference in water consumption per household in summer is expected. Results indicated that residents don't water their plants frequently during winter. Moreover, xerophytes are popular household plants in Malta and require less water than plants growing in temperate climates. Residences in a rural setting are expected to require more water for gardening purposes. Green roofs in urban environments are being endorsed as a means of alleviating floods in Germany (Arthur and Wright, 2005) and might be encouraged in Malta, particularly in Msida. Apart from being aesthetically pleasing and hydraulically beneficial, they offer thermal insulation in winter, and also reduce the "heat island effect" that is present in urban conurbations such as Msida.

Expressed demand for rainwater

A significant 35.4% of participating households are currently using harvested rainwater to different extents. This result is indicative that the tradition of RWH has not been completely lost. 33.6% of households collect it in underground cisterns and a low 1.8% harvests it in plastic containers.

From the expressed purposes of use it was seen that the principle function of rainwater is in appliances or activities that require secondary class water quality. Approximately 30% claim that rainwater is of better quality than mains water where gardening is concerned. Some stated that rainwater is optimal for laundry because of it being softer than mains water. Its use is deemed to prolong the life span of a washing machine. Similar views on the good quality of harvested rainwater were shared by those who utilise it for drinking and cooking.

64% don't collect rainwater at all, whilst 6.7% claimed of having collected rainwater in the past but have abandoned such practice due to reasons pertaining to health and water quality.

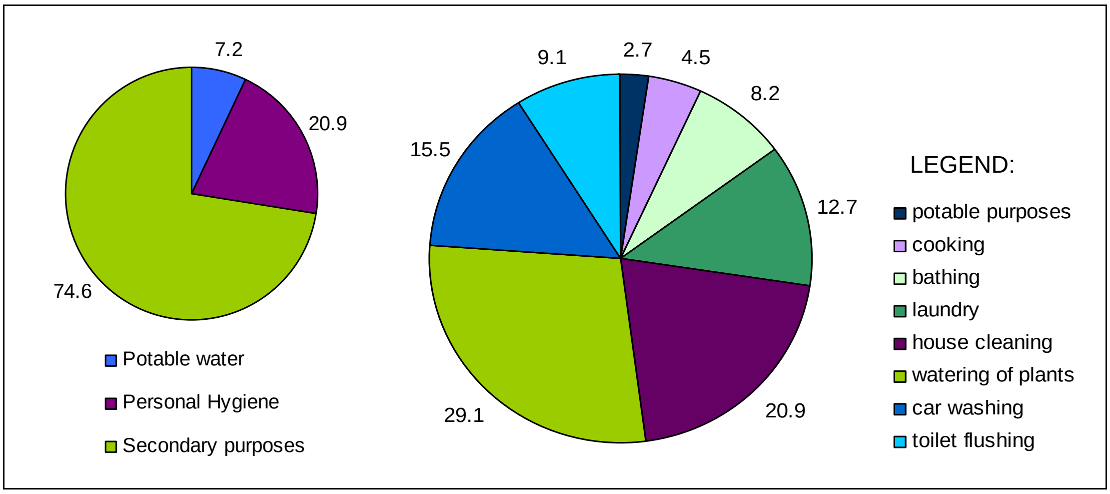


Figure 10: Percentages of expressed uses for rainwater in the home

PHYSICAL POTENTIAL OF RAINWATER HARVESTING: DEMAND AND SUPPLY

Since average precipitation supply, its seasonal and temporal distribution and the average household microcomponent demand have been defined, the performance of a RWH system in an average Maltese household, utilising 21 years of rainfall data could be modelled.

Calculating the potential rainfall supply by estimating runoff

The amount of supply of rainwater was calculated using the following variables:

i. Average rainfall
ii. Average roof catchment area (m^2)-this was carried out in the Msida catchment using GIS maps. Different residence types have different roof sizes and different resident population-to-roof area ratios, thus it was crucial that residence types were mapped. An average roof size had to be inferred from the highest frequency of roof size covering the area. An average area of $100m^2$ was decided since over 70% of the residences were of this size.
iii. The runoff coefficient was needed to account for losses due to spillage, leakage, infiltration, catchment surface wetting and evaporation (Gould and Nissen-Petersen, 1999).

The equation used to establish the supply of rainwater is the following:

$\mathbf{S = R \times A \times C_r}$		
Where	S =	mean water supply in m^3
	R =	mean annual rainfall in mm
	A =	roof catchment area in m^2
	C_r =	Runoff Coefficient

Based on the statistical analysis on demand that preceded this section, the following statistically significant assumptions could be deduced:

i. The demand was calculated by taking the mean household size of the sample population which was 3.05*.
ii. The average per capita consumption rate was taken to be 70 l/head/day.

* 3.12 is the mean household size value that stated in the NSO Household Budgetary Survey (2002)

iii. The calculation of rainwater demand per family was restricted to its use for secondary class purposes since this carried the most significance, accounting for 64% of the total water demand in a household. This is equivalent to a demand of 45 l/capita/day.
iv. Since the seasonal variation in demand was mainly bathing and gardening, variation in demand was not considered in the modelling. Bathing requires certified high quality water whilst gardening in a Maltese urban environment consumes very little due to limited green space.

Results

From the above combination of factors the following were deduced:

i. The volume of rainwater supplied including cumulative supply.
ii. The volume of 'top-up' water needed when harvested rainwater ran out.

The average amount of days in the 21-annual period studied, in which a rainwater surplus was reported, amounted to 92% meaning that whether there is sufficient rainwater supply to cater for average household needs is not an issue. As expected it is the storage capacity of a cistern that appears to be problematic, especially in an area where space is limited, as in Msida. This incurs high costs related to the excavation of big enough cisterns, which does not make RWH feasible at the small domestic scale.

The analysis of the potential volume of rainwater that can be stored over a 21-year period demonstrated that in the September-February interval, the generated surplus rainwater, or that rainwater that is not consumed, can amount to a maximum of 48700 litres in a month. This means that a 50m^3 storage capacity tank is required in order for no water to be lost via runoff. Such considerable storage space was needed in a total of 6 out of the 21 years (1990-92, 1995-96, 1997-2000). Storage space of this size, at the domestic scale means that the cost to construct a cistern will rise exponentially with size. The estimated surplus for most years was between 30m^3 to 40m^3 and thus a storage capacity of 30m^3 would collect most surplus runoff (Figure 11).

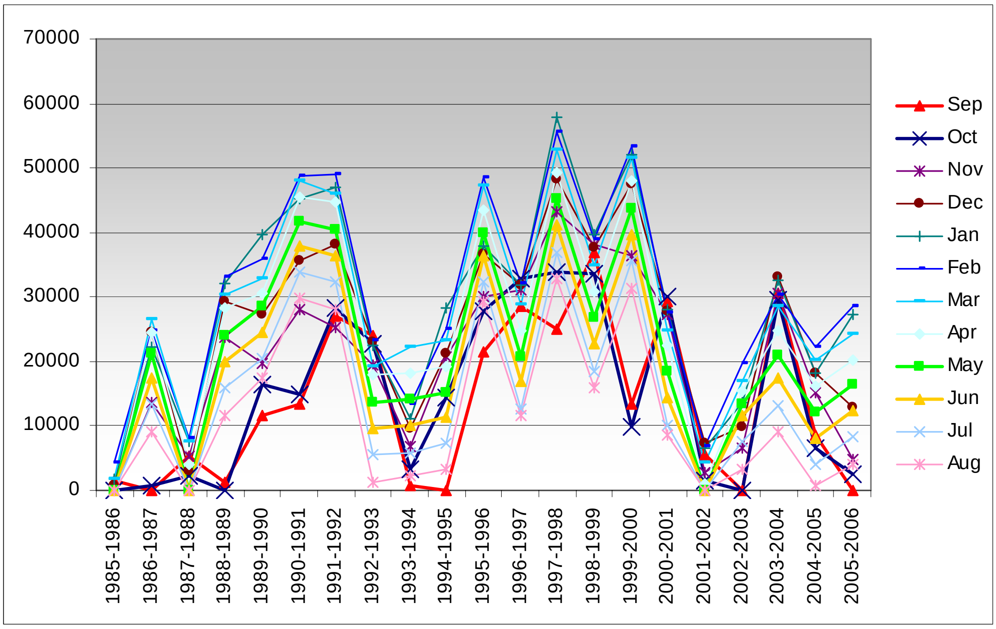


Figure 11: Cumulative surplus rainwater that is not consumed monthly.

Insufficient rainwater to meet the domestic demand was limited to 8.3% of the total period modelled. Moreover, the shortfall in the total was extremely low with deficits ranging from a mere 0.01m^3 to 4.1m^3. As Figure 12 shows the deficit in rainwater supply occurs mainly in July and August or immediately after a dry year, in September. It is only during these times that additional water is needed to carry out secondary class requirements in the home.

The seasonal variability in rainfall means that a first flush system to clean roofs of excessive debris is required at least once a year after the prolonged 4-5 month dry season and before the heavy rains start in September. The August rains could be utilised for this purpose, though as the average 21-annual data for this month reveals, it's not always sufficient for roof cleansing.

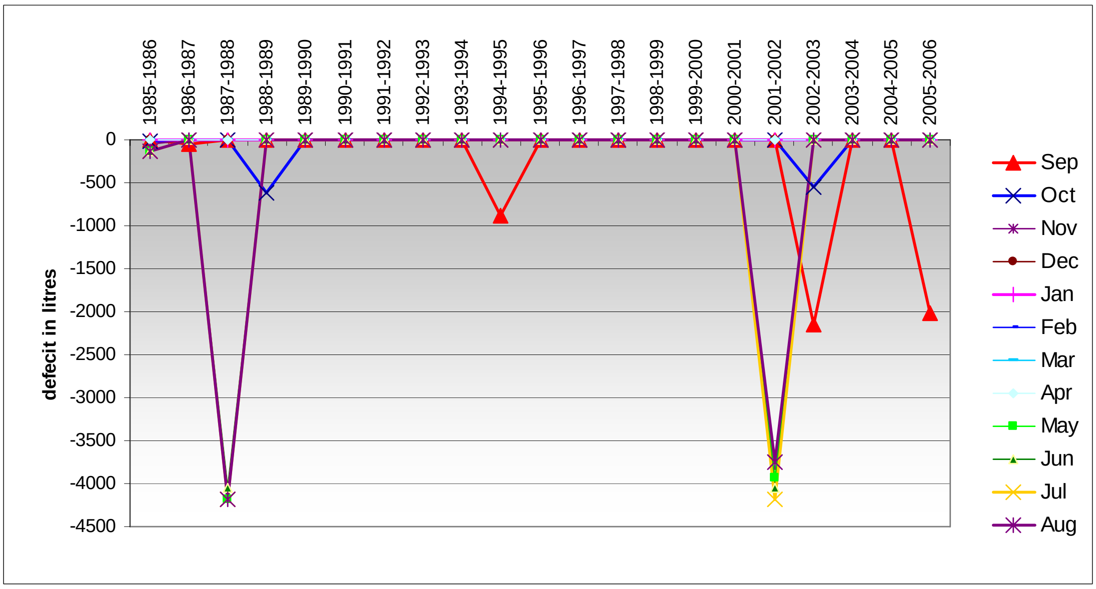


Figure 12: 8.3% of all days in the 21 year period fell short in supplying the required supply of water.

Future climate change trends could also influence the duration, intensity and frequency of rainfall events. Drago *et al*., (2000) postulate that there is a 50% chance that mean annual temperatures will rise by a further 3ºC by the end of the century. Precipitation trends are less reliable but an expected decrease of approximately 17% may amount to a reduction of 60mm in annual rainfall by 2100. Less rain is also expected in autumn which in turn will aggravate aridity due to a rise in temperatures combined with enhanced evapotranspiration. Attard (2006) claims that due to climate change Malta is already experiencing more dry spells '*with rain falling in heavier downpours on less wet days*.' This emphasizes the importance of a need for RWH but simultaneously highlights the present uncertainty with regards to rainfall patterns, natural supply and induced demand.

When considering the total combined averages of all the years together the average size of the cistern required to collect the mean 21-year rainwater was just 20m^3. This amount fails to consider the significant variations in monthly rainfall from year to year and highlights the importance of daily data as the optimal data type to be used for modelling the performance of a RWH system (Thomas, 2000). This level of detailed data was unavailable. Nevertheless, the modelled output of monthly data still provides a reasonable estimate of the optimum storage capacity for harvested rainwater and to what degree an average household can depend on the physical availability of the resource.

THE SOCIAL ENVIRONMENT

An enabling legislative environment for the enforcement of RWH in Malta

The legal enforcement of domestic RWH in Malta dates back to the time of the Knights of St. John. Acknowledging the lack of water resources, the Order enforced a law that each dwelling built in Valletta was to have an underground cistern excavated and no front garden was permitted. In recent decades RWH at the domestic level was envisioned as a vital source of water and has been included within principal legislation. The first official document, the *Code of Police Laws,* obligates that all dwellings require a cistern in good condition of a capacity of 3m^3 per 5m^3 of floor area of each room of the dwelling. The dwelling is defined as "*any mezzanine, room store or other building made chiefly of stone or other material used in building construction*."

The ratification of this code is chiefly ensured through the enactment of the *Development Planning Act* (Chapter 356, 1992) which oversees the requirements needed for a permit to develop land in order for it to be issued. This is the chief responsibility of MEPA. All development is monitored to ensure that it is carried out in adherence to this Act. Additionally MEPA has issued a Policy Design Guidance document on buildings in 1998 and revised in 2005; setting out conditions of rainwater storage for residential and non-residential developments.

Further to this, conditions for both small and large-scale developments are given. Water cisterns for small and large-scale developments require a volume of 30% and 60% of the total roof area respectively (DPG, 2005). Also the '…*cistern shall be completed and available for use prior to the development hereby permitted being first brought into use*'.

Considering existing legislation, one would expect that any type of residence would have some form of cistern or underground reservoir. However, the current situation is a far cry from this. Several factors have impeded the ratification of these laws and range from issues pertaining to ones of an entirely physical nature to ones related to development, planning, and legal issues as elaborated on in the next section.

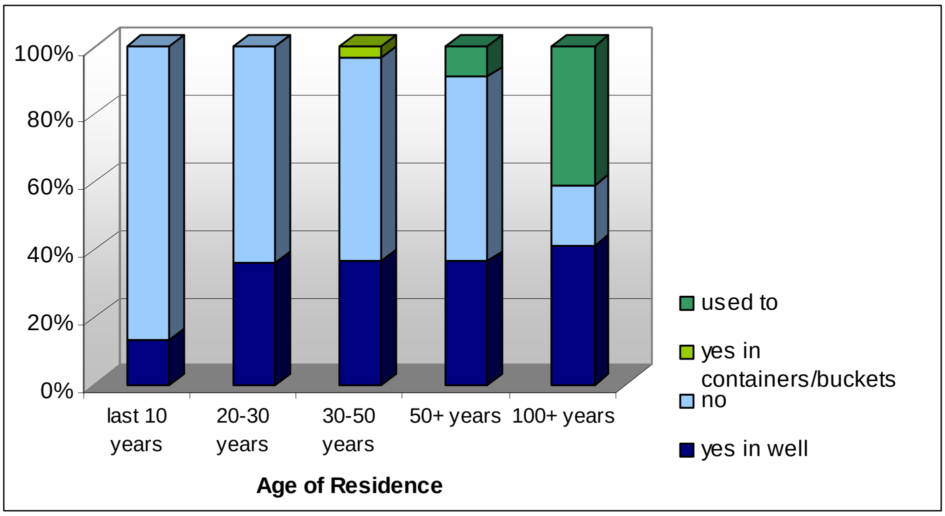
Legal Water Rights and Land Ownership

Generally, dwellings constructed prior to WWII and during the 1950's, used to have a cistern. Several older houses dating back 100-200 years ago also have a well which are usually very deep and bell-shaped. As revealed by some elderly, most houses constructed in the 1950s in Msida have a communal well which is accessed from two openings. A significant relationship resulted between current rainwater collection and residence age. (Figure 13 and Table 5).

Chi-Square Test RES_AGE*RWH

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Squar	44.598[a]	12	.000
Likelihood Ratio	38.649	12	.000
Linear-by-Linear Association	6.023	1	.014
N of Valid Cases	109		

Figure 13 and Table 5: A significant relationship between age of residence and domestic rainwater collection.



Strikingly, 41% of houses that are 100 years or older, and 9% of those 50 years plus, *used to* draw water from a well. The reason being is that most of the houses sharing a well have been demolished and apartment blocks are now rising in their stead. As a result, old cisterns have either been blocked, filled with demolished waste or have become inaccessible due to water right ownership uncertainties.

2% of the sample respondents identified that this was a major constraint. An additional 1% mentioned that their cistern was in disrepair due to the penetration of tree roots. This implies that the existing capacity of older wells is declining due to lack of maintenance and indeed, a lack of surveillance from MEPA's end to ensure that structural assets such as old wells are maintained and used in new developments.

Few residences built in the last 40 years have a well mainly because the law has not been enforced. The lack of enforcement was elucidated by means of the Professional interviews (PIs) whereby 15 of the stakeholders interviewed identified this to be a major constraint. The PIs exposed that there isn't a clear cut definition of the roles and responsibilities of neither the competent authorities nor the contracted architects that draw the final plans. One MEPA officer stated *"…enforcement is also a problem. MEPA is not responsible for monitoring whether the cistern is constructed according to plan or not. It is the architect's responsibility."* Another officer admitted that MEPA is not '*strict on ensuring that the size of the cistern is according to permit condition, but lately we're requiring architects to indicate the outline of the reservoir on plan, to enable enforcement officers to check that it has been constructed. I'm not sure if they do check, however.*'

A third planning officer stated that *"…It is however hardly enforced since MEPA does not feel that it should be responsible for enforcing this clause but feels that it should fall directly under the responsibilities of the MRA".* Similar statements from various stakeholders reveal the gaps and overlapping responsibilities of some authorities. This often gives rise to misunderstandings between departments and results in failure to carry out responsibilities; public sector loss of credibility follows. This calls for the identification of gaps in key legislation in order for there to be jurisdictional coherence.

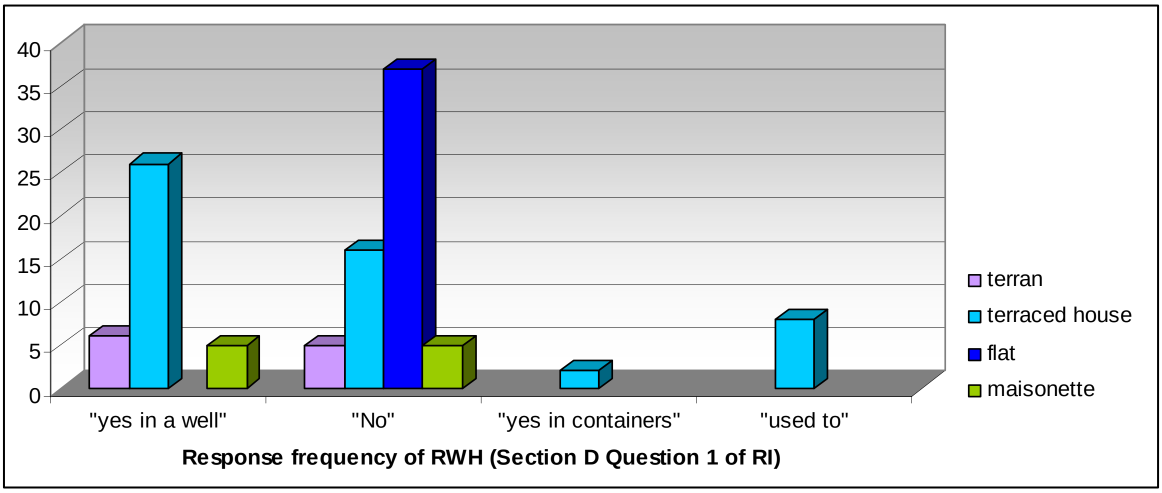
Planning and development

Related to the issue of land ownership is that of planning and development. Lack of space for cistern construction was by far the most mentioned constraint in both the RI and PIs. Space is a significant problem in any small island which means that land is a seriously contested issue and as shall be seen, shapes the Maltese lifestyle. Thus casual planning can limit the potential of RWH.

(i) Lack of space and residence type

Recent years have seen the sudden boom of high rise buildings in Malta. The Structure Plan (MEPA, 2000) favours the construction of flats rather than terraced houses because of the increasing problem of space incurred by a growing population. In 2000, 62% of all housing development permits were apartments and only 18% were terraced houses (MEPA-HTP 2002). Residence type and rainwater use were found to be highly related (Table 6). The use of communal cisterns is not commonly found in flats or maisonettes due to several reasons pertaining to maintenance and management inconveniences.

Firstly, as most professionals pointed out, multipurpose use of roofs for breeding race-pigeons, keeping pets, washing carpets, amongst others, can give rise to water quality concerns and a consequent '*yuck factor*'. Similar concerns are shared with occupants of single floor houses (in Maltese '*terran'*) that have a well but don't own the roof catchment. Another difficulty is how to ensure occupants are responsible for the maintenance of the cistern and roof tanks. Thirdly, apportioning of collected rainwater to different household demands may be of nuisance.



Chi-Square Tests Residence type*RWH

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	31.921[a]	9	.000
Likelihood Ratio	43.614	9	.000
Linear-by-Linear Association	5.256	1	.022
N of Valid Cases	110		

Table 6: A significant association between residence type and rainwater collection.

The Civil Code (Chapter 16) does concede the sharing of communal wells between two or more occupants. This is "*subject to his obligation to refund the owner of the tenement in which the excavation of the cistern was commenced, one half of the expense incurred.*" (441:1). The Code, however, fails to pay heed to regulations for communal wells in apartment blocks. This calls for the need of contractual agreements on the allocation and use of communal wells, whereby the owner of the cistern and roof is determined together with the means of allocating the resource. The 'residence type' map (Figure 14) reveals that apartment blocks are extremely popular in the water-receiving zone of the Msida catchment area. This could entail loss of potential storage capacity if a solution is not found to promote RWH.

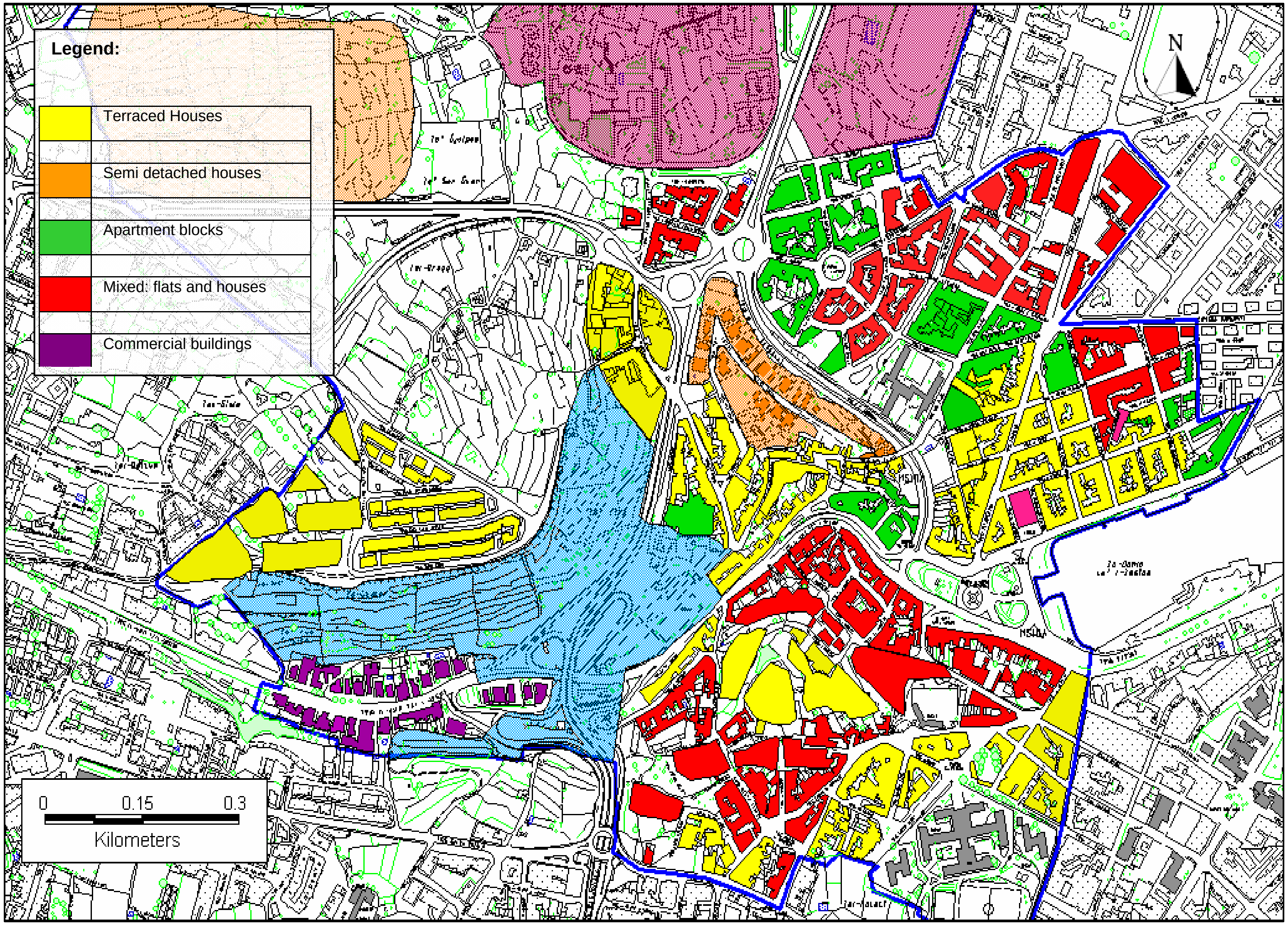
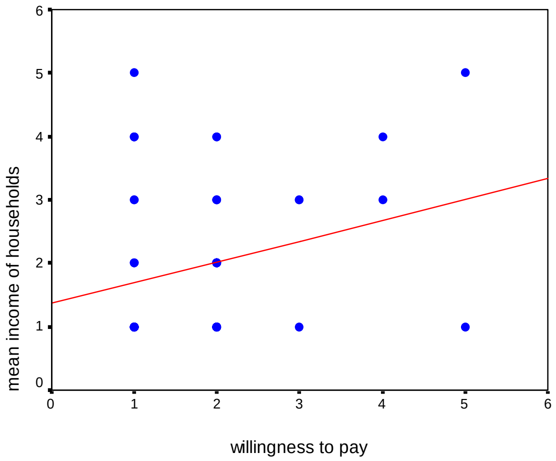


Figure 14: Map of the Lower Msida catchment showing extent of housing by residence type.

(ii) Willingness and ability to pay for a cistern

Willingness to pay for a well was conveyed through the RI, whereby residents that had no well and wished one, were asked the amount they were willing to pay if the government offered financial aid (Table 7). Out of the 59% that presently have no well, 73% stated that they desired one.

Figure 15: The ability to pay for a cistern is dependant upon average income.



Willingness to pay if well costs Lm 5000	**Percentage of sample population**
Over 70%	3%
Between 60 - 70%	4.7%
Between 50 – 60%	51.6%
Less than half the price	37.5%
0	3%

Table 7: Willingness to pay for a cistern

The ability to pay was tested by comparing the mean income of each household against willingness to pay. A statistically significant result (p-value 0.012, $\alpha = 0.05$) and positive correlation resulted (Figure 15); reflecting the low shadow price of rainwater and its infrastructure despite the fact that cisterns cost a fortune to construct. It also highlights the necessity for government aid.

(iii) The opportunity cost of a garage vs. that of rainwater

Another setback concerns garages that have to be constructed underground to save space, often meaning that space required for cisterns is taken up by garages. The response rate of whether occupants would forego a garage for a well is shown in Figure . As portrayed, the majority replied that a garage is of greater financial value since a residence with a garage would carry a higher market value than that with a cistern. Moreover, parking space has become increasingly scarce due to a high rate of cars per household (2 cars), making it the fifth highest in Europe (Eurostat, 2003). The 11.8% of the occupants that preferred a well stated that they expect a rise in the water prices in the future due to the unstable fuel prices.

The garage and cistern issue boils down to planning and enforcement. MEPA has never considered garage space as a threat to RWH. A planning officer at MEPA revealed that some developers construct a cistern below the garage or at the same level to it, in the case that the garage is constructed at basement level. Yet even here there is a limit to how deep one can excavate since physical obstacles may arise depending on the site of construction and the mean sea level. This again points in the direction of the importance of the architects' involvement in its planning.

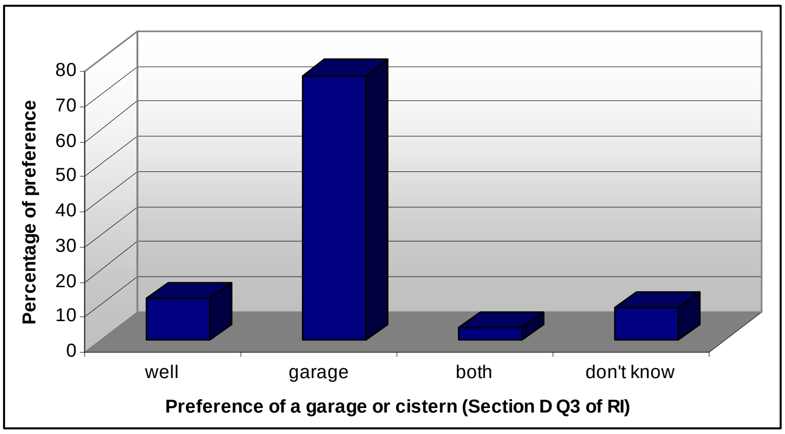


Figure 16: The opportunity cost of a garage is much higher than that of water.

(iii) Physical obstacles

One of the issues identified by the RIs was the proximity of the dwellings' foundation to sea level. The incursion of sea water into cisterns was identified to be a common phenomenon in coastal low-lying areas, particularly those of Msida and Birżebbuġa. Another issue (Role *in* PI) was the proximity of quarries to residences. Malta's sole natural resource is limestone and several quarries litter the island particularly in the south-western part. Strong blasting activities can breach cisterns and raise maintenance costs. Alternatively, quarries could be used as district cisterns since space is being readily made available.

Water Quality and health related issues,

Two social constraints affecting public acceptance of RWH is that of health and water quality. 4% (mainly elderly) of those who utilised well water identified health to be a limiting factor. Back ache, loss of sight, and lack of physical strength were stated reasons that hinder rainwater use since most elderly feel that using tap water was a safer and more accessible means of getting a secure water supply.

Often it is the multipurpose use of roofs that give rise to rainwater quality concerns. Samples of rainwater have shown that total faecal coliforms are higher than acceptable quality standards making the water unfit for drinking (Sammut, personal communication). Pigeon racing[4] is a very popular sport in Malta and cages are usually kept on roofs inducing high bacteriological counts in rainwater. In fact, Hermann and Schmida (1999) do not advise roofs with considerable pigeon activity to be used for RWH, whatever the purpose of use.

In the RI a number of occupants stated that they would not mind using rainwater for bathing if the quality and safety of the water was within their control. Yet as noted in both the RI and PIs, air pollution is beyond their remit and an increase in construction works in the area has resulted in higher observed wind blown suspended particles in rainwater making it turbid and unacceptable for use. This also means an increase in well cleaning costs with prices ranging from Lm 40[5] for a few centimetres to Lm 200 for 1m. Climate change could have a similar effect (Evans *et al.*, 2006) due to changes in wind direction rendering some roofs more prone to sediment collection. Deep cisterns or tanks can solve the problem of sediment if sufficient time is left for particles to settle and water pumps are placed ¾ way up so as not to disturb the settled solids. Chemical pollution due to feast fireworks that are arsenic and benzene based was also identified to be a potential problem.

The Department of Health does not advise the use of rainwater for potable purposes or for uses where rainwater will come into contact with the human body unless treated to the standards stipulated by the DWD (98/83/EC). Their main concern pertains to Legionnaires disease. Unlike other countries *cryptosporidium* has not yet been identified a problem in Malta since surface waters on the island are negligible (Bonnici *in* P I).

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[4] the extent of this pigeon activity in Malta is unknown
[5] Currency rate Lm 1 = £ 1.62

Taste and turbidity have been observed to be the ruling factors that influence public perceptions on drinking water quality. Results show that only 2.7% of occupants drink well water which is treated through UV infiltration or ceramic filtration. Utilising rainwater for drinking requires frequent monitoring and treatment. This incurs a further cost that is not always financially feasible, considering that subsidized water supplied by the WSC is cheap and increased quality has to be assured because of the DWD. Nevertheless, even if rainwater is not used for first class purposes, good water quality for secondary use is important.

The importance of Education

The above issues urgently call for educational campaigns and published materials that target all age groups. Education is essential because an informed public is key to the successful implementation of RWH. The publication of planning guidelines for roof catchment systems similar to those designated in other countries such as in Hawaii (Macomber, 2001) and Australia (DEHAA, 1999) is needed. This way occupants are taken through step by step procedures for setting up a RWH system. Also needed is the guideline for wider society responsibilities such as blasting controls, dust limitation, and pigeon controls.

As seen, water conservation is lacking in the younger age groups. The WSC carried out a series of intensive educational campaigns for families through different media (WSC 94/95 and 96/97 report). In 1996 theatrical performances aimed at primary school children were organised to educate them on the use of harvested rainwater and related water quality issues; followed by the provision of a little booklet entitled *'il-bir'* (the Well) (Figure 18). Unfortunately this education campaign has not been continual.

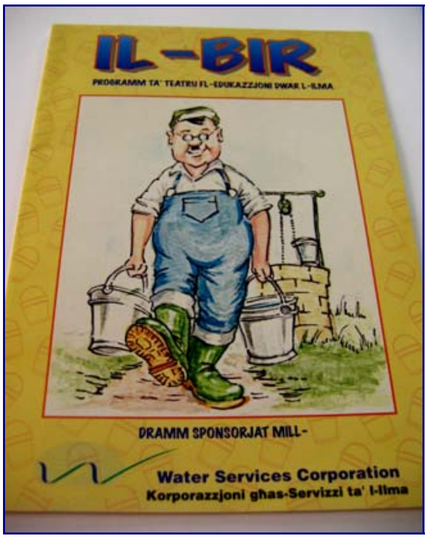

Figure 18: Educational material published by WSC

THE ECONOMIC ENVIRONMENT

The cost-effectiveness of RWH at the household scale

In addition to the constraints mentioned it is necessary to estimate how cost effective RWH is at the household scale. The full costs of a RWH system were considered. The cost of constructing a cistern ranges from Lm5000–Lm7500 depending on different contractor quotas. Basing the estimate of rainwater consumption per household (taken as 3 members) per day as 135 litres; and a total maximum cost of a cistern as Lm 7500; this would imply that the total cost of rainwater in an average lifetime of 50 years would amount to Lm 3.12/m^3 per person/day. This value is not economically feasible when the subsidized rate for water currently stands at Lm 0.16/m^3 per person/day. Illegal abstraction further makes cistern construction unfeasible with offers of only Lm1500 to dig a borehole to the water table. The additional expense of treating rainwater to potable standards, therefore, does not make economic sense either.

It must be pointed out, however, that wells constructed over 200 years ago are still in use today and thus provide sustainable benefits. If old cisterns are maintained and renovated at a cost of approximately Lm 400 and considering that the well has to be cleaned frequently, then over a lifespan of 50 years the cost of rainwater would stand at Lm 0.16/m^3 per person/day. This makes it an economically viable option since such a cost is equal to the government's current subsidized rate.

As seen, current costs of underground cisterns are exceedingly high. When considering that average family incomes are around the Lm 6000 p.a. bracket (42.7% of population) well construction is not financially attractive and calls for either financial government incentives or soft loans. Surface poly plastic tanks of much smaller capacity are noticeably cheaper[6], but limit the volume of rainwater that can be collected and space is also an issue unless small tanks fit into the garage. These costs would best be incorporated into new buildings.

With or without RWH?-the costs and benefits of RWH at the National Scale

Reverse osmosis and groundwater abstraction

RO technology is considered to be the most efficient means of producing water in Malta. EU directives have been one strong driving force since the high level of treatment attained by RO provides the advantage of compliance with strict drinking water quality standards. Cost-effectiveness is the second major driving force with recent desalination technology making RO more economically attractive (Elsevier, 2005).

As highlighted by Riolo (PI), the cost reduction in desalination has been brought about by both membrane innovations and energy recovery equipment (Bindra and Abosh, 2001; Avlonitis *et al.,* 2003). The amount of water that can be produced by one membrane element has more than doubled in the last 20 years (Elsevier, 2005). This efficiency has coupled with proficient RO feed pumps, reduction in pressure losses through membrane elements; innovative pressure exchanger efficiency and also increased efficiency of the PROP or Pelton wheel (Mauth *et al*., 2003).
The Maltese experience in desalination is a long one, dating back to 1886 (Riolo, 2000) and has led to a switch from MSF to RO, with a dramatic increase in specific energy consumption efficiency. Andrews (1986) claims that the total cost of desalinated water, excluding capital recovery, is US \$0.62/m^3 (Lm 0.21). A recent World Bank report (2004) calculated a total costing of Lm 0.28/m^3 to produce 32,000m^3/day (Table 9)

[6] a 10m^3 tank for instance costs US \$ 1,211.58 (Lm 841) (www.watertanks.com)

Table 9: Source: Adapted from N. Wade Jerba 2001 in World Bank (2004)

Process	MSF	RO	RO & brine booster
Capital costs in Lm (millions)			
Distillers installed	11.73		
RO plant installed		9.758	8.67
Seawater Intake and Outfall	0.952	0.68	0.612
Foundations and buildings, 15%	1.904	1.564	1.394
Financing during construction, 10%	1.462	1.19	1.054
Engineering and contingency, 10%	1.462	1.19	1.054
Total	17.51	14.382	12.784
Unit Costs, in Lm/m^3			
Energy			
-heat	0.08228	0	0
-power	0.03706	0.04352	0.03604
Operation and Maintenance	0.04284	0.04284	0.04284
Spares	0.02788	0.01122	0.01122
Chemicals	0.00816	0.01598	0.01598
Membranes	0	0.0374	0.03332
Capital charges	0.15674	0.1292	0.11492
Total Lm/m^3	**0.35496**	**0.28016**	**0.25432**

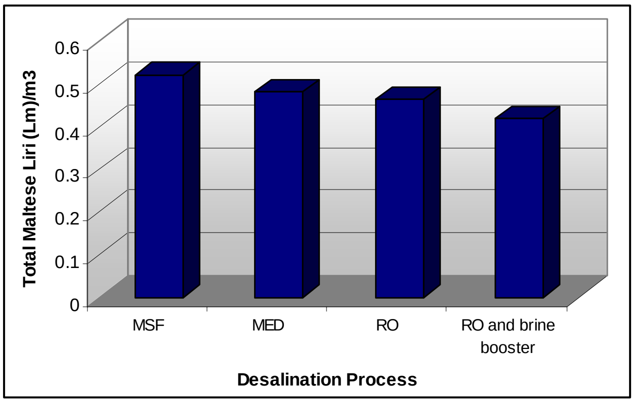

Figure 19: A comparison of the costs of different desalination techniques.

Politically desalination has been attractive too. As the AD chairman pointed out (Vassallo *in* PI) politicians are interested in large-scale projects that demand public recognition. Also politicians have a short-term mentality, as do consumers, which make drought an effective incentive for RO (Elsevier, 2005) and possibly a favourite over domestic RWH. However as the MRA observes, depending on RO entails a high level of risk. RO production is still 3 times the cost of producing groundwater (MRA, 2005) and a number of non-monetary environmental externalities have to be taken into account including air quality and CO_2 emissions as well as chemicals that are disposed of in the marine environment, which can have negative impacts on benthic ecosystems (World Bank, 2004). An economic assessment of these environmental costs needs to be considered when comparing RWH and RO.

Since brackish water is cheaper to desalinate than sea water (UNEP, 1992), district RWH reservoirs can prove to be more economically viable since they would provide a dilution to RO plants, reduce energy consumption and also solve the quality problem. RWH has the advantage of providing an emergency supply of water to households if for operational reasons, desalination facilities fail or there is an accidental offshore oil spill which renders RO inadequate. RWH can further substitute groundwater which is already under threat.

Flood Alleviation and infrastructure

RWH and its capacity to alleviate floods is an enormous benefit that cannot be quantified in monetary terms due to the snowball effects it would have on road and sewage infrastructure. The Msida case is able to shed light on this since, as the Minister pointed out, this catchment has the most significant flooding problem nationwide. As the topographic contours in Figure indicate, all rainwater that falls in the upper and central reaches of the catchment drain towards Msida. Currently 26.5% of occupants dispose their rainwater directly to the sewer despite this being illegal practice, thereby placing the sewerage infrastructure under pressure.

Two thirds of the Msida catchment is built up (Figure 20). Development encroaches upon the valleys located in this area meaning that flooding in the lower reach and adjacent areas is exacerbated during peak storms. A total of 600,000m^3 can fall in a period of 12 hours. (Figure 22)

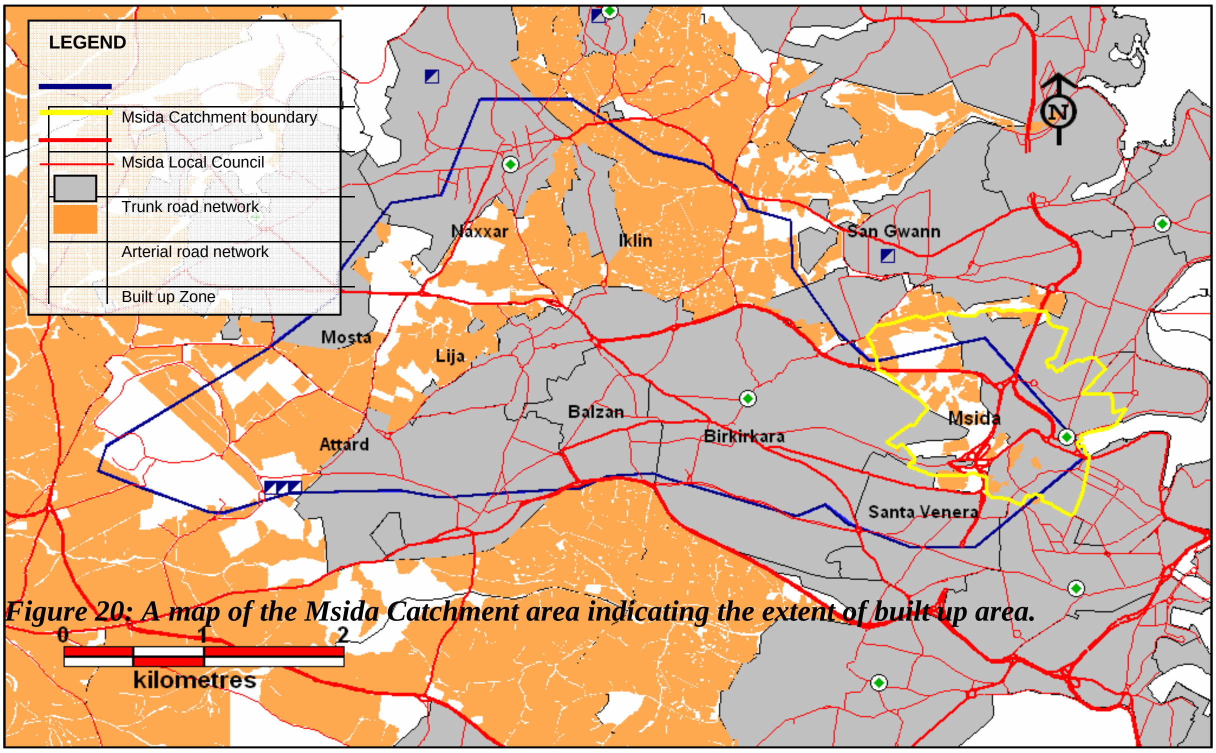

Figure 20: A map of the Msida Catchment area indicating the extent of built up area.

In the North Harbours Local Plan (2006) MEPA has set up a flood mitigation policy for the Msida catchment. This policy (NHMP03) (MEPA, 2006b) designates the undeveloped section of the Msida Valley as an ODZ (Out of development zone) meaning that no development is permitted within this area. RWH throughout the catchment should also be considered as an effective solution. If one were to estimate the total runoff that can be collected in the catchment, and if 50% of the households were to collect 30m^3 of rain, this would reduce the total runoff by 43% (8750 households X 30m^3 = 262 500m^3).

It is also essential that agricultural RWH is encouraged in the northern parts of the catchment near Naxxar and Birkirkara so that waters are harnessed and stored for various communal, agricultural or commercial purposes. A number of historic reservoirs constructed during the time of the Knights and under British rule exist; however as asserted by key PIs they have been neglected or damaged due to road construction and could be restored.

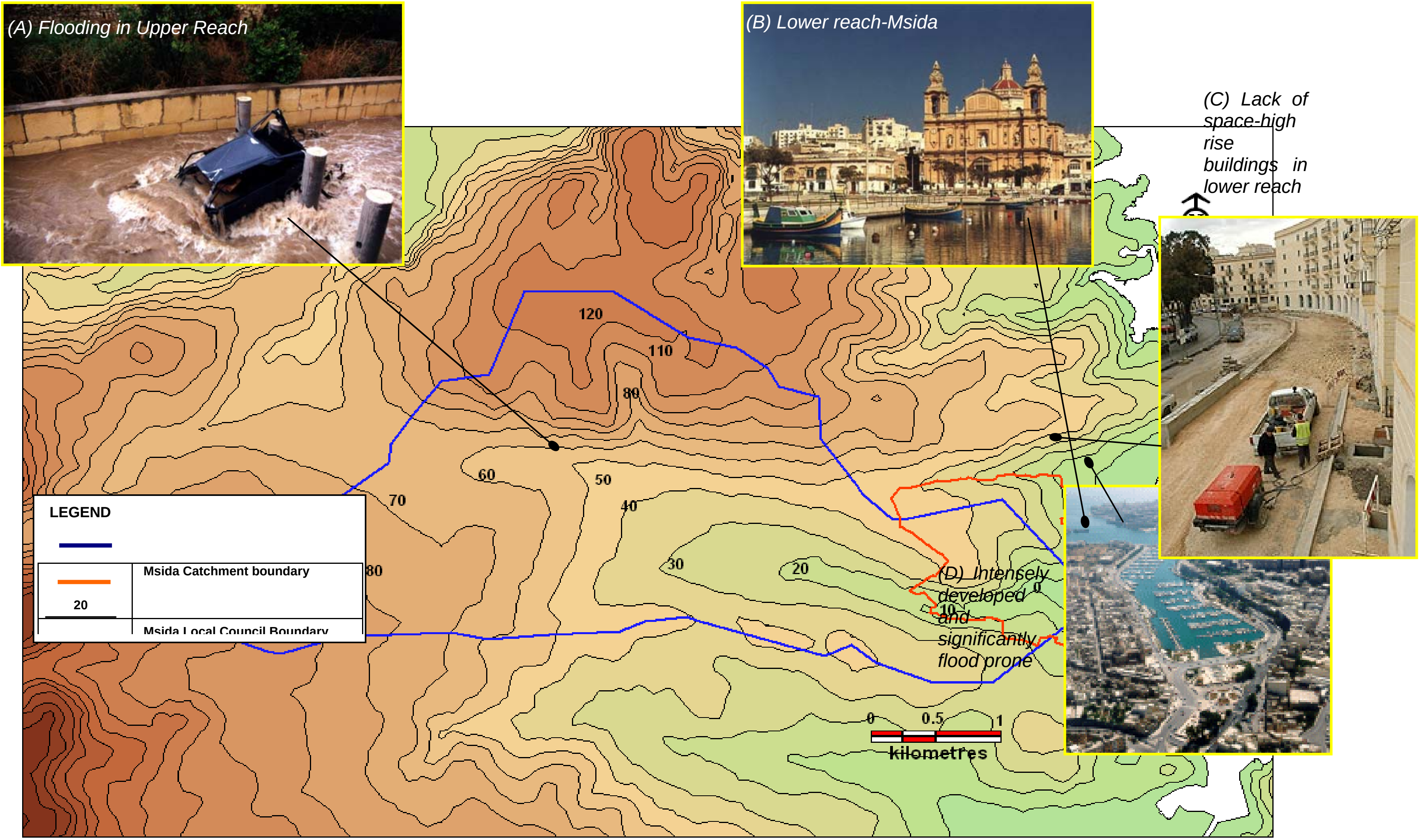

Figure 21: Topographical contour heights of the Msida catchment area

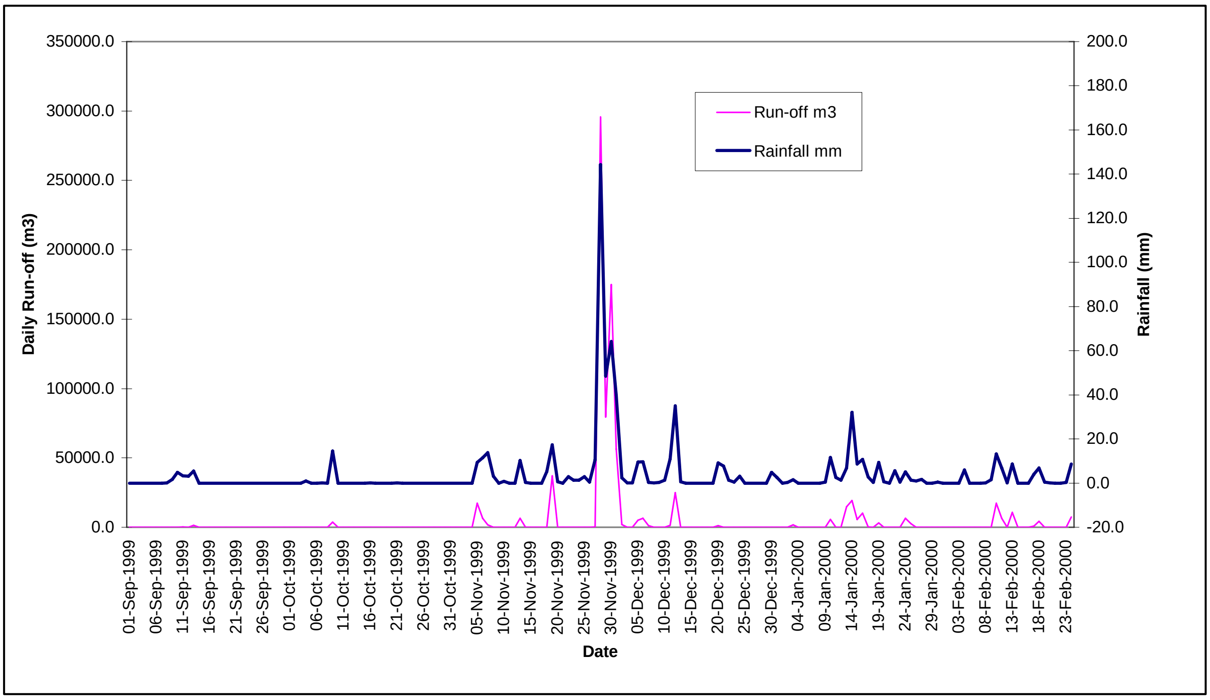

Figure 22: A snap shot of the excessive amount of runoff in the Msida local council.

Source: Water Service Corporation

Summing up: is there a potential?

Based on the premise of IWRM, the integrated approach towards assessing the potential of RWH in Malta has synthesised the outcomes of a physical, social and economic analysis into one coherent whole. Literature reviews together with residential and professional interviews have enabled the identification of issues unique to small island environments. A concentration of a wide spectrum of human activities in a small area is bound to cause water quality and quantity problems, rising property prices and simultaneously rising value of car space. Thus, the case of Malta can be said to be a microcosm of situations similar to other islands, particularly those in the Mediterranean and the Pacific.

A high population density and a deficiency in natural resources including water, has for centuries positioned RWH as a vital part of principal legislation in Malta. Despite this long history of endorsing RWH, several constraints have hindered its use and echo the inherent problems of limited space, urbanisation and increased air pollution, lack of planning and contested land ownership. Yet, these problems can be unravelled with careful planning, rigorous enforcement and education.

The 21-year precipitation data have shown that there can be no question as regards the physical potential for rainwater collection. Moreover, historical experience has aided the technical set up of an average Maltese household to make use of this rain most effectively. However with time land has become increasingly contested for and high rise buildings have taken over, destabilizing the traditional ways of rainwater collection. With the shift to high rise buildings and condominium use even bigger storage cisterns are required to be sufficient for residential needs. But even before cisterns can be utilised in apartment blocks, ways and means of reaching a consensus on how to allocate the collected water and properly maintain the roof catchment and RWH infrastructure, have to be reached.

Further to this, contested space and low water prices have induced a low opportunity cost of RWH infrastructure such as wells and reservoirs and a low shadow pricing of water as a resource. Ironically, however, the capital cost of a cistern is high when compared to the average yearly income of Maltese households. RWH therefore, would only be cost effective at the local scale for those households that already have a cistern. Some existing cisterns are over 100 years old and still in good use; however, low water tariffs do not give the public any incentive for their renovation. Similarly old road reservoirs are blocked by the careless planning of new road construction, further curtailing the potential of RWH.

Ineffective regulation due to excessive government intervention has meant that factors contributing to the enhancement of RWH such as enforcement, proper planning, strong environmental and economic regulation, have become diluted in a concoction of illegal activities that hinder their implementation. Illegal abstraction has made RWH financially unattractive financial. Low government subsidized water tariffs coupled with high cistern maintenance and construction costs, further discourage this potential. Lacking government based incentives or soft loans means that RWH is difficult to implement at the local scale.

Alternatively, as was seen in both the RI and PI, a significant social recognition of the importance of RWH at both the bottom-up and top-down level exists. 58.2% of the public believe that RWH should be promoted at a larger scale despite the fact that only 38% utilise it today at the domestic level. Most of the water professionals and key implementation bodies share this recognition. At political level there exists a propensity for large-scale projects that harvest rainwater, since simple, small-scale RWH will never catch the public's eye and therefore their full potential is undermined.

A cohesive and cooperative partnership between leading competent authorities and other levels of society carries significant weight. The professional interviews exposed varying degrees of cooperation and communication between different authorities, governmental departments and NGOs. Notable cooperative relationships were found to exist between the Health Department and the MRA; the WSC and the MRA and also between MEPA and the MRA, but responsibilities overlap. It was also apparent that NGOs seem to be marginalised. Such independent organisations are necessary stepping stones required to link the end users with the service providers and regulatory bodies. Similarly independent private consultants in the water sector also require warranted attention due to the great potential they can offer in terms of innovative and cost–effective technological solutions

A collaborating administrative and regulatory environment ensures that various policies such as that of energy and water can be integrated coherently. The need for a water policy that ties all these strands together in one coherent whole is yet to be formulated. Through this policy RWH should be seen in the light of other unconventional alternatives such as greywater reuse, stormwater use and treatment of sewage effluent. Its implementation, however ultimately hinges on public approval and on stakeholder cooperation which means that a proficient and on-going communication strategy has to be integrated too.

RECOMMENDATIONS FOR FURTHER STUDY

Future modelling research could build on what was performed in this study. It has been highlighted that there is a dire need for a detailed microcomponent demand analysis in Malta; not merely because of its contribution to the understanding of domestic water demand in relation to rainwater consumption but also due to it being fundamental to the future forecasting of demand for IWRM in general. Lifestyle contributions and influences in demand should also be studied. This would provide educational campaigns with evidential backing to direct most energy to target specific groups since factors such as age, purchasing power and work influence the patterns of water consumption in each household.

Catchment-scale rainwater collection modelling should also be encouraged; results should be amalgamated with stormwater runoff management to determine the reduced impact on structural assets and infrastructure if RWH is implemented, such as in agricultural, commercial and industrial sectors. Further analysis should be concentrated on the technical and financial feasibility of RWH systems for non-residential users. Large-scale systems have the potential of outperforming small-scale residential systems mainly due to economies of scale and increased surface area for the storage of larger volumes of water.

A spectrum of government incentives offered to any type of user, including non-residential, requires investigation. The economic feasibility of these incentives is necessary, since this would enable politicians to make the right choice concerning which incentive provides the optimal outcome. It would also be a valuable tool to policy makers and regulatory bodies to propose the most economic viable way RWH could be promoted at the national scale. If all the above measures are taken into account and a practical coherent framework is set up, countries worldwide could harvest every raindrop that falls.

References

Andrews, W.T. 1986. The Malta seawater RO facility-Update on the first 2 years of operation. *Paper presented at the Second World Congress on Desalination and Water Reuse*, 17-22 November, 1985, Bermuda.

Angelakis A.N. 2003. Wastewater Recycling and Reuse in Malta. Malta Resources Authority.

Agarwal, A. and Narain, S. 1997. *Dying Wisdom. Rise, fall and potential of India's traditional water harvesting systems*. New Delhi, India, Centre for Science and Environment.

Albrechsten, H.J. 2002. Microbiological investigations of rainwater and greywater collected for toilet flushing. *Water Science and Technology*. 46: 311-316

Appan, A. 1998. *Return of the Native-Rainwater harvesting: The revival of simple Methods*. Paper presented as a keynote address at the National Conference on the Potential of Rainwater Harvesting: Traditions, Technologies, Policies and Social Mobilisation, in New Delhi, Centre for Science and Environment (CSE).

http://www.humanscape.org/Humanscape/new/jan01/hs010108.htm (accessed on the 15th May 2006)

Arthur, S., and Wright, G.B. 2005. Technical Note: Recent and Future Advances in roof drainage design and Performance. *Building Services, Eng. Res. Technical,* 26 (4) 337-348.

Avlonitis, S.A., Kouraumbas, K., and Vlachakis, N. 2003. Energy Consumption and Membrane Replacement cost for seawater RO desalination plants, *Desalination*. 157: 151-158.

Axiak, V., Gauci, G., Mallia, M., Mallia, E., Schembri, P.J. and Vella, A.J. 1999. *State of the Environment Report for Malta 1998*, Environment Protection Department, Malta.

Bailey, K.D. 1987. *Methods of Social Research*. 3rd Edition. Macmillan, New York.

Ball, A., and Styles, M. 2003. Measuring microcomponents for demand forecasting. In: Maksimovic, Butler and Memon (eds.) *Advances in Water Supply management*. pp.673-680

Bindra, S.P. and Abosh, W. 2001. Recent developments in water desalination. *Desalination*. 136:49-46

Brouwer, R., and Pearce, D. 2005. *Cost Benefit Analysis and Water Resources Management*. Edward Elgar Publishing, Cheltenham, UK.

Burnell, D. 2003. Lifestyle and its effects on domestic water use. In: Maksimovic, Butler and Memon (eds.) *Advances in Water Supply management*. pp.647-656

Buscemi, P.E. 2003. *Integrating Water Resource Management – Analysis of the St. Thomas US. Virgin Islands, Water Market*. Master of Engineering in Civil and environmental Engineering dissertation. Massachusetts Institute of Technology.

Chanan, A. and Woods, P. 2006. Introducing total water cycle management in Sydney-A Kogarah Council Initiative. *Desalination,* 187 (1):11-16

Collins, R. 2003. Hard sell for new water. *Water and waste water*, 14 (**4**):39-40

Coombes. P.J. and Kuczera. G. 2002. Integrated Urban water management: moving towards systems understanding. 2nd National Conference on Water Sensitive Urban Design, University of Newcastle, Australia.

Corral, V., Frías, M., Pérez, F., Orduna, V., and Espinoza, N. 2002. Residential water consumption, motivation for conserving water and the continuing tragedy of the commons. *Environmental Management* 30 (**4**) 527-535

Civil Code. Chapter 16. 1874. p20-41 http://docs.justice.gov.mt/lom/legislation/english/leg/vol_1 (accessed on 25 July 2006)

Code of Police Laws. Chapter 10. 1854. p.103-108.

http://docs.justice.gov.mt/lom/legislation/english/leg/vol_1 (accessed on 25 July 2006)

Day, M. 2003. The comprehensive monitoring of a rainwater recycling system and its potential impact on future water supply demand. In: Maksimovic, Butler and Memon (eds.) *Advances in Water Supply management*. pp.525-533

Delia, C. 2004. Economic considerations regarding markets for water in the Maltese islands, Malta Resources Authority.

DEHAA, 1999. *Rainwater Tanks-their-Selection, Use and Maintenance*. Department for Environmental Heritage and Aboriginal affairs, Government of South Australia.

Development Planning Act. Chapter 356. 1992.

http://docs.justice.gov.mt/lom/legislation/english/leg/vol_1 (accessed on 25 July 2006)

Dolgen, D., Baban, A. and Alpaslan, M.N. 2006. Use of rainwater cistern systems, in *Sustainable Water Management 1-2006: Concepts towards a Zero-Outflow Municipality*, MEDA Program, p.11-14

Drago A., Gauci, F.T., Camilleri, M. Cordina, G., Mallia, A., Muscat, J., Vella, L., and Zammit, A. 2000. Assessing the vulnerability and adaptation to climate change. *Towards a National Action Plan.* University of Malta, Physics Department.

Edwards, K., and Martin, L. 1995. A methodology for surveying domestic water consumption. *The Chartered Institute of Water and Environmental Management* 9 (5): 477-488

Elsevier. 2005. Desalination: Looking into the future. *Filtration and Separation*, March 2005. wwww.fitsep.com/latest-features/feature_articles/050320-desalination.html

Eurostat, 2003. *Statistical Yearbook on Candidate Countries*. Office for Official publication of the EU, Luxembourg.

European Parliament and Council of the European Union. 2000. Directive 98/83/EC *Drinking Water Directive*, Official Journal of the European Communities L327

European Parliament and Council of the European Union. 2000. Directive 2000/60/EC *Water Framework Directive*, Official Journal of the European Communities L327,

Evans, C.A., Coombes, P.J. and Dunstan, R.H. 2006. Wind, rain and bacteria: the effect of weather on the microbial composition of roof harvested rainwater. *Water Research*, 40 (1) 37-44

Finn, M., Elliott-White, M., and Walton, M. 2000. *Tourism and Leisure Research Methods - Data Collection, analysis and interpretation*, Pearson education, Edinburgh.

Gale and Dillon, 2005. Strategies for managed aquifer recharge (MAR) in semi-arid areas. UNESCO IHP, Paris.

Gardiner, V., and Herrington, P. 1986. *Water Demand Forecasting: Proceedings of a Workshop*. Geo Books, Norwich.

Gould, J. and Nikksen-Petersen, E. 1999. *Rainwater Catchment Systems for domestic supply: Design, Construction and Implementation*, Intermediate Technology Publications, London.

Handia, L., Madalitso Tembo, J. and Mwiindwa, C. 2003. Potential of rainwater harvesting in Urban Zambia. *Physics and Chemistry of the Earth,* 28 :893-896

Hassan, M. 2005. Arsenic poisoning in Bangladesh: spatial mitigation planning with GIS and public participation. *Health Policy*, 74 (**3**) 247-260.

Hasse, R. 1989. *Rainwater reservoir above ground structures for roof catchment*, Humanity development library. A Publication of Deutsches Zeutrun für Entwicklungs- technologien - GATE In: Deutsche Gesellsdoft für Technischezusammenarbeit (GTZ) Grubh, Antwerp, Belgium.

Hatibu, N. Mutabazi, K. Senkondo, E.M. and Msangi, A.S.K. 2006. Economics of rainwater harvesting for crop enterprises in semi-arid areas of East Africa. Agricultural Water Management, 80 (**3**):74-86

Hermann, T. and Schmida, U. 1999. Rainwater utilisation in Germany: efficiency, dimensioning, hydraulic and environmental aspects. *Urban Water* 1: 307-316

Herrmann, T., & Hasse, K. (1997). Ways to get water: rainwater utilization or long-distance water supply, Water Science Technology 36 (**8**) 313-318.

Intermediate Technology Development Group. 2000. (ITDG) Rainwater Harvesting. Knowledge and Information Services: the Schumacher Centre for Technology and Development.

Jacks, G., Bhattacharya, P., Chaudhary, V. and Singh, K.P. 2005. Controls on the genesis of some high-fluoride groundwaters in India. *Applied Geochemistry*, 20(**2**) 221-228

Jeffrey, P., Seaton, R.A.F., Parson, S.A., Judd, S., Stephenson, T., Fewkes, A., Butler, D., and Dixon, A. 2000. An Interdisciplinary approach to the assessment of water recycling technology options. *Int. J. Water*. 1(**1**) 102-117.

Jonnalagadda, S.B., Makadho, J., Matinde, N., Karimanzira, R.P., and Makaraiu, A. 1994. Chemical composition of rainwater and air quality in Zimbabwe, Africa. *The Science of the Total Environment*. 144 (3) 261-271.

Kerala News. 2006. Suggestion to include rainwater harvesting in curriculum. *Kerala News*, 1st August 2006. http://www.newkerala.com/news3.php?action=fullnews&id=3156

(accessed on 4th August 2006)

Lazarova, V., Hills, S., and Birks, R.2003. Using recycled water for non-potable, urban uses: a reviews with particular reference to toilet flushing. *Water Science and Technology* 3 (**4**) : 69-77

Lazarova, V., Levine, B., Sack, J., Cirelli, G., Jeffrey, P., Muntau, H., Salgot, M., and Brissaud, F. 2001. Role of water reuse for enhancing integrated water management in Europe and Mediterranean countries. *Water Science and Technology* 43 (**10**) : 25-33

Li, F., Cook, S.E., Geballe, G.T., and Burch Jr, W.R. 2000. Rainwater harvesting agriculture: an integrated system for water management on rainfed land in China's semiarid areas. *Ambio*, 29 (8) 477-483

Limb, M., and Dwyer, C. (Eds.). 2001. Qualitative *Methodologies for Geographers- Issues and Debates*. Arnold, London.

Lye, D.J. 2002. Health risks associated with consumption of untreated water from household roof catchment systems. Journal of the American Water Resources Association. 38: 1301-1306.

Maltatoday, Sansone, K. 2005. 'Rising Fuel oil prices may trigger higher surcharge'. 3 July 2005. www.maltatoday.com (accessed on 23 March 2006)

Maltatoday. 2005. 'Fuel to the Fire'. 23 October 2005. *Maltatoday*. www.maltatoday.com (accessed on 23 March 2006)

Maltatoday, Debono. J. 2006. 'The People's tribune. Interview with Labour MP Marie Louise Coleiro'. 5 February 2006. *Maltatoday*. www.maltatoday.com (accessed on 23 March 2006)

Macomber, S.H.P. 2001. Guidelines on rainwater catchment systems for Hawaii. College of Tropical Agriculture and human resources. University of Hawaii, Manoa.

Mangion, M.L. 2001. *Carrying Capacity Assessment for Tourism in the Maltese Islands*, Ministry for Tourism, Malta Tourism Authority, St. Julians. pp.38

Mauth, T., Gabar, M. and Oklejas, Jr. 2003. *Minimizing RO energy consumption under variable conditions of operation*. Desalination. 157:9-21.

Mbilinyi, B.P., Tumbo, S.D., Mahoo, H.F. Senkondo, E.M. and Hatibu, N. 2005. Indigenous knowledge as a decision support tool in rainwater harvesting in Tanzania. *Physics and Chemistry of the Earth*. (???) :792-798

Milestone Report. 2001. Report D1. *Household Water Security in Sri Lanka using Domestic Roof water Harvesting.* ERBICI8-CT98-0276.

Miller, T. 2002. Urban rainwater: from pollution source via value-added design. *A Report for the Hixon Centre for Urban Ecology and in fulfillment of F&ES 546a*. Yale School of Forestry and Environmental Studies.

MEPA, 1992 Structure Plan. www.mepa.org.mt (accessed on 28th June 2006).

_____. 2002. Housing Topic Paper. www.mepa.org.mt (accessed on 28th June 2006).

_____. 2006 State of the Environment Report. www.mepa.org.mt (accessed on 16th June, 2006).

MNFP.2005. History of water use in the Maltese Islands. National Malta Focal Point. www.emwis.org.mt (accessed on 20th June 2006)

MRA. 2004 Economic Characterization of the Maltese Water Catchment district. Malta Resources Authority, Marsa, Malta. www.mra.org.mt (accessed on the 22nd March, 2006)

Movahed, D. A. A. 1997. Sacredness of rainwater in Iranian culture and its harvesting for drinking and agricultural purposes. In: *Proceedings from the 8th International Conference on rainwater Catchment Systems*, April 21-35, 1997 1: 827-291

NSO. 2002. *Environmental Statistics*. National Statistics Office, Valletta

_____. 2006. Census of Population and housing 2005, Preliminary report. National statistics Office, Valletta. 29p.

Pandey, N. D; Gupta, A.K; and Anderson, D.M. 2003. Rainwater harvesting as an adaptation to climate change. *Current Science*, 85 (**1**): 46-59

Pearce, F. 2006. Water Water everywhere in: *Prospect Magazine*. Issue:22 accessible from http://www.prospect-magazine.co.uk (accessed on 26th March 2006)

Po, M; Kaercher, J.D; and Nancarrow, B. 2003. Literature Review of Factors influencing Public Perceptions of Water Reuse. CSIRO Land and Water Technical Report 54/03, Australian Water Conservation and Reuse Research Program

Prinz, D. 1996. Water Harvesting: Past and Future. In: Pereira, L. S. (ed.), *Sustainability of Irrigated Agriculture Proceedings*, NATO Advanced Research Workshop, Vimeiro, 21 – 26.03.1994, Balkema, Rotterdam, 135 – 144

Rajabu, R.M.K. 2005. The role of participatory problem analysis in performance improvement and sustainable management of rainwater harvesting systems: A case study of Makanya village, Tanzania. *Physics and Chemistry of the Earth*, 30 (**16**):832-839

Riolo, A. 2001. Maltese experience in the application of desalinated technologies. *Desalination*, 136: 115-124.

Rogerson, P.A. 2001. *Statistical Methods for Geography*. Sage Publications, London.

Sharma, S. 2002. Rainwater harvesting has yet to protect India from drought. *Water Lines*, 21 (**4**) 22-24.

Smet, J. and Moriarty, P. 2001. DGIS Policy Supporting Paper: Rooftop Rainwater Harvesting, IRC. DELFT

Spinks, A.T., Dunstan, R.H., Harrison, T., Coombes, P. and Kuczeru, G. 2003. Water Quality treatment in domestic rainwater harvesting systems. In: proceedings of the 28th *Intenational*

Hydrology and Water Resources Symposium 10-14th November, 2003. The Institution of Engineers, Australia.

Spinks, A.T., Coombes, P., Dunstan, R.H., and Kuczeru, G. 2006. Thermal inactivation of water-borne pathogenic and indicator bacteria at sub-boiling temperatures. *Water Research*, 40 (**6**):1326-1332

Stuart, D. 2001. On-site runoff mitigation with roof top rainwater collection and use. King County Department of Natural Resources. Water and Land Resources Division.

Tate, J. 2000. Water Supply in the UK: towards a more sustainable future? Sustainable development. 8. 155-164.

The World Bank. 2004. *Seawater and Brackish Water Desalination in the Middle East, North Africa and Central Asia. Annex 5 Malta*. DHV Water BV. The Netherlands and BRL Ingénierie, France.

____. 2004. *Seawater and Brackish Water Desalination in the Middle East, North Africa and Central Asia. Final Report*, DHV Water BV. The Netherlands and BRL Ingénierie, France.

Thomas, T. 1998. Domestic water supply using rainwater harvesting, *Building Research and Information*. 26 (**2**): 94-101

____. 2004. RWH Performance predictor for use with coarse (i.e. monthly) rainfall data. *Domestic Roofwater Harvesting Research Programme*. DFID UK Departent for International Development.

Troy, P., Holloway, D., and Randolph, B. 2005. *Water Use and the Built Environment: Patterns of Water Consumption in Sydney*. City Futures Research Centre, Research Paper 1, University of New South Wales, Sydney.

UNEP. 2000. Rainwater Harvesting and Utilisation – An Environmentally Sound Approach for Sustainable Urban Water Management. An Introductory Guide for Decision Makers. United Nations Environmental Programme.

http://www.unep.or.jp/ietc/Publications/Urban/UrbanEnv-2/index.asp (accessed on the 15th May 2006)

UNEP. 1998. *Sourcebook for Freshwater Augmentation in Small Island Developing States* United Nations Environmental Program.

http://www.unep.or.jp/ietc/Publications/Urban/UrbanEnv-2/index.asp (accessed on the 15th May 2006)

Water Lines. 2002. Household water treatment 2. Technical Brief no. 59. *Water Lines* 21(2) 15-18.

WRAS. 1999. Conservation of Water an IGN for Architects. Designers and Installers, Water Regulation Advisory Scheme Information and Guidance Note, Issue 1 No 9-02-03

WSC. 1995. Annual Report 1994-1995. Water Services Corporation, Luqa.

____ 1997. Annual Report 1996-1997. Water Services Corporation, Luqa

____ 2005. Annual Report 2005. www.wsc.com.mt (accessed on May 16th 2006)

Wei, H., Long Li. J. and Gang Liang, T. 2004. Study on the estimation of precipitation resources for rainwater harvesting agriculture in semi-arid lands of China. *Agricultural Water Management*, 71(1) 33-45

Zaizen, M., Urakawa, T., Matsumoto, Y. and Takai, H. 1999. The Collection of rainwater from dome stadiums in Japan. *Urban Water* 1(**4**) :355-359

Managed Aquifer Recharge: Lessons learned from the AGRAR study, India.

Ian Gale[1]

Abstract

The construction of myriad aquifer recharge check dams and other interventions to harvest rainwater in rural India is successful in capturing the majority of available runoff, but this is not sufficient to replenish depleted aquifers in many areas without reduction of groundwater abstraction. Research sites were instrumented and monitored, over two monsoon seasons, in order to quantify the components of the water balance of check dams at three locations. Different hydro-meteorological and geological environments were selected and the results were interpreted in the context of the quantity of natural recharge in the watershed, availability of water and storage capacity in the aquifer, as well as likely downstream impacts. Natural recharge to the aquifers studied was estimated to be between 40 and 120 mm, to which recharge structures contributed an additional 5 to 12 mm equivalent volume, concentrated around the structures. This is a significant increase but only represents about 1% of rainfall in the semi-arid areas, the majority satisfying the soil moisture deficit and evapotranspiration. The study also attempted to relate the physical effectiveness of the structures to socio-economic impacts on the local communities in the context of water management practices, but this is not discussed in this paper.

Keywords: Groundwater management, Managed Aquifer Recharge, India

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1. Introduction

Most interventions take as granted that watershed treatment leads to increased recharge and rising groundwater levels (or slower decline) in the watershed as a whole. These changes, in turn, are assumed to lead to improvements in water supply, drought resilience and, ultimately, more sustainable livelihoods for participating communities. However, the specific impacts of recharge interventions (as opposed to watershed development more generally) are rarely evaluated or documented on a scientific basis. This has raised concerns that Managed Aquifer Recharge (MAR) is being seen too much as a panacea for water supply problems and groundwater overdraft, without the necessary evaluation of its potential in different climatic, agro-ecological, hydrogeological and socio-economic conditions; hence the initiation of the research described here.

2. Methodology

In order to quantify the impacts of recharge structures on the hydrology of a catchment and the hydrogeology in the immediate vicinity, three research sites were instrumented and monitored. These sites were selected to be representative of a range of hydrological as well as socio-economic environments. The physically-based study involved a series of baseline surveys plus the monitoring of flows and water levels over time in order to quantify the components of the water balance, both of the selected recharge structures and their relationship to the micro-watershed. The baseline surveys included: the mapping of the geology and its hydrogeologically important features; topographical surveys to delineate the catchments of the structures and to map in detail the contours of the structures themselves. The components that were monitored over time included: rainfall and other climate data, to allow evaporation from the free-standing water in the recharge structure to be quantified; groundwater levels in existing wells and boreholes drilled for the project in the vicinity of the structure; water-levels in the structure itself; surface flows into and out of the structure; sediment flow into the structure and how this changed its storage volume; pumping tests to estimate the hydraulic properties of the aquifer. Water samples were also collected to determine if the quality of the water in the local drinking wells benefited from the water recharged by the structure. The monitoring in all the case study areas was undertaken over the period June 2003 to March 2005; this covered two dry seasons and the intervening two wet seasons. However, all data were only available for one wet season (2004) and two dry seasons (2004 and 2005).

In addition, data were collected on the livelihoods of the local communities, the operation and maintenance of schemes and the socio-economic impacts of the structures. By comparing the results of the socio-economic and physical elements, it was hoped that the impact of the recharge structures on the livelihoods of local communities could be examined. These elements of the research are described elsewhere (Gale et al., 2006), the focus of this paper being on the physical impacts of the recharge structures on the hydrology at the structure and micro-watershed scales.

3. The Research Sites

The three case studies were located in the Satlasana Taluka north Gujarat state, in the Kolwan Valley, west of Pune, Maharashtra state and in Kodangipalayam watershed in Coimbatore District, Tamil Nadu state. The research was undertaken by local non-government organisations (NGOs) and a university, having had, in each case, a history of involvement in supporting the social and economic development of the area, including water management issues.

3.1 Satlasana, Gujarat

Satlasana Taluka is located in the foothills of the Aravalli Hills in the north of Gujarat State. Agriculture is the primary livelihood of most households in the region. The region suffered a prolonged drought between 1999 and 2002 but agriculture remains the primary income source and a heightened awareness of the need to conserve and enhance groundwater resources has resulted in the construction and reinstatement of a number of recharge structures.

The Aravalli Hills which surround the villages studied form a well-defined catchment of approximately 20 km^2. The area is semi-arid; the average annual rainfall is around 650 mm, with rainfall occurring from late June until the end of September. There are typically 30 to 35 days of rainfall in a year.

The main aquifer in the catchment is formed by shallow weathered and fractured granitic rocks. These are overlain in the upper regions of the valley floor by thick layers of sediment (15-20 m) weathered from the hillsides. The main part of the valley floor is moderately undulating.

Drinking water in the area is provided by piped network from the Dharoi reservoir in the Aravalli Hills. This is a recent development, recognising the extreme hardship that was suffered as a result of the recent drought, and also the high fluoride concentrations that have been found in some drinking water wells.

3.2 Kolwan Valley, Maharashtra

The Kolwan Valley sits in the foothills of the Western Ghats of Maharashtra. The Walki River drains the valley, which is well defined by the steep basaltic hills that surround it. The valley, with an area of 80 km^2, is the home to around 15,000 people, still reliant on agriculture as their main source of income. Government-funded watershed improvements have been ongoing in the valley over the past decade. The level of activity in this area has risen significantly in recent years, including the construction of a number of recharge structures.

The majority of Maharashtra state has a semi-arid climate; however, Kolwan is located on the eastern slopes of the Western Ghats, the mountain range that runs from north to south along the western edge of peninsular India. As a result, rainfall is significantly greater here, 1800 mm/a on average, although highly variable. The rain occurs mainly during a single monsoon season, generally from June to October.

The Kolwan Valley is surrounded by basaltic hills; at their maximum height, 1100 metres above sea level (masl), lying significantly higher than the valley floor, which at its lowest point is 570 masl.

The detailed local geology comprises a series of eight basalt units (lava flows). Each unit has a compact, less weathered lower section and a fractured/jointed, more weathered upper section; the latter having the capacity to store more groundwater, being more permeable and therefore a much better aquifer. The check dams at Chikhalgaon are all located on the upper section of one of the basalt units.

3.3 Kodangipalayam, Tamil Nadu

The area under investigation centred on the Kodangipalayam micro-watershed, to the north east of the city of Coimbatore, the main structure monitored being the Karanampettai check dam. The recharge structures under investigation in this case study were, however, constructed by the Government of Tamil Nadu in the 1970s.

The Kodangipalayam watershed consists of two micro-watershed with a total area of 5.0 km^2. The population of the watershed is approximately 5700, with around 500 households. Rainfall in this region of India occurs in two seasons as a result of the southwest monsoon (June to September) and the northeast monsoon (October to December). The regional average total annual rainfall is 650 mm, measured at Sulur (7 km from Kodangipalayam).

The area is underlain by shallow weathered crystalline hard-rocks (charnockites, migmatites and banded gneisses) which have relatively low groundwater storage capacity. Hydrogeological surveys of the whole Kodangipalayam watershed area showed a significantly different groundwater system in the west of the watershed compared to that in the east. The catchment of the Karanampettai check dam covers an area 1.41 km^2. Detailed topographical surveys were undertaken to map the shape of the structure so that water levels in the structure could be related to the volumes stored.

4. Results

4.1 *Satlasana, Gujarat*

In 2004, the rainfall in the study area was 441 mm, around two-thirds of the average rainfall, 693 mm, measured between 1989 and 2004. The majority of the rains occurred in two periods, in mid June and the first half of August, at the beginning and the end of the normal period of the wet season. The rains resulted in three periods of inflow to the recharge structures being monitored. The Bhanavas check dam overflowed on two occasions, for 11 minutes and 5 hours and 50 minutes respectively.

The rate of water level decline after the first filling of the check dam is approximately 225 mm/day. Potential evaporation during this period is estimated to be 5 mm/day. The rate of water level decline for the latter period of the last filling is in comparison 78 mm/day, still significantly greater that the potential evaporation, which was ~3 mm/day during this period.

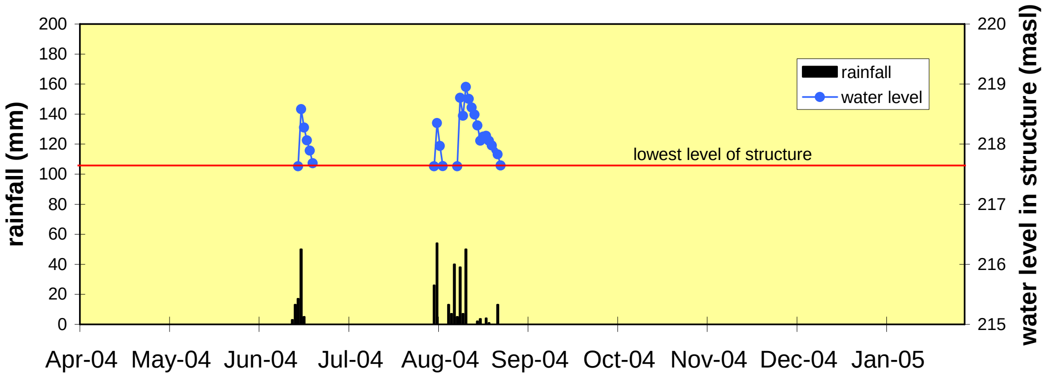

Figure1 Response of the water level in the Bhanavas check dam to rainfall.

4.2 *Kolwan Valley, Maharashtra*

Based on estimates of run-off and other data, including groundwater level fluctuations, the natural recharge to the basaltic aquifer (the vast majority of which occurs where the upper section of the basaltic units is at outcrop) was estimated as 105 mm for the 2004/05 season. This is limited by the capacity of the aquifer to accept recharge; at the end of the dry season in 2004, groundwater levels in the aquifer were typically two to three metres below ground.

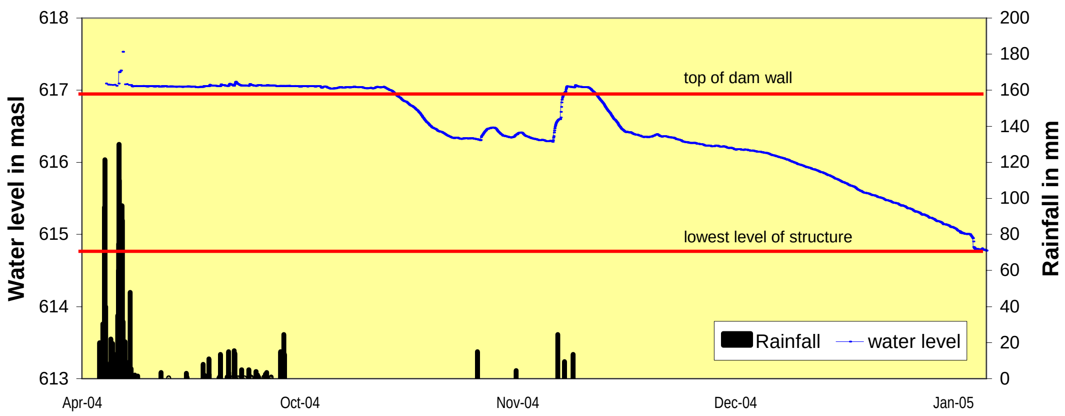

Figure2 Response of the water level at Chikhalgaon (CD3) to rainfall in the 2004.

A water balance was undertaken for CD3 for the 2004/05 season. For the dry season, (November 2004 to January 2005) from the time the dam stopped overflowing and there was no flows into the structure, until the structure was empty, a volume equivalent to about 1.7 mm over the whole catchment infiltrated. The majority of this infiltration is, however, rapidly discharged downstream and the best estimate of recharge relating to the structure is an equivalent depth of 12 mm over the catchment area.

Monitoring groundwater levels in piezometers in the vicinity of CD3 showed that the structure does have some impact on groundwater levels. However, the rise in levels that can be attributed to the structure would appear to be negligible a couple of weeks into the dry season. Recharge to the aquifer would appear to move quickly through the shallow aquifer system. Indeed it is thought that much of it exits the aquifer short distances downstream as baseflow to the stream.

4.3 Kodangipalayam, Tamil Nadu

Although much of Tamil Nadu was suffering a sustained period of below average rainfall, including the Kodangipalayam watershed, the rainfall over the two monsoon periods of 2004 was 753 mm at the

Sulur meteorological station, about 40% higher than the long term average annual rainfall of 527 mm.

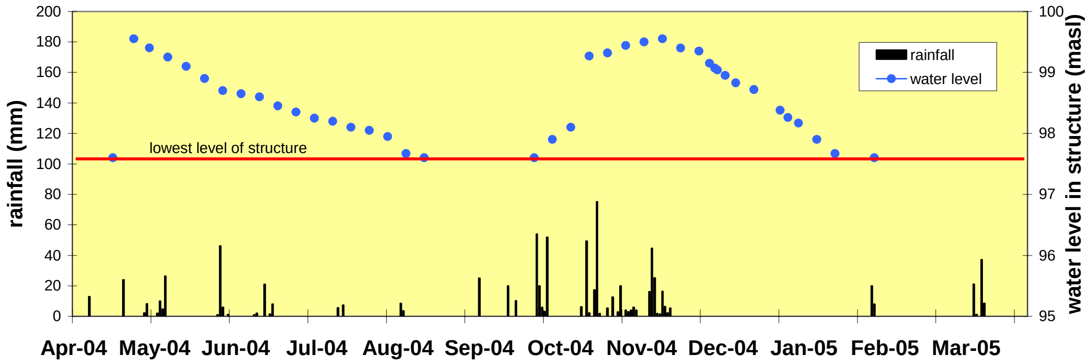

Figure 3 Response of the water level at Karanampettai check dam to rainfall in the 2004

The main structure under investigation, in Karanampettai village, did not overflow during the first monsoon in 2004. The structure did fill during the second monsoon season and it overflowed for a period of about 15 minutes, equivalent to about 4000 m^3. It is estimated that the Karanampettai structure captured 80 % of the runoff within its catchment.

The water balance took into account the amount of water that evaporated from the open water, which fluctuated closely around a value of about 4 mm/day. In the period between the southwest and northeast monsoons, sediment that had been deposited in the structure was removed. In April/May 2004 the rate of decline in water level reduced from 23 mm/day to 12 mm/day; attributed to the lower permeability silt layer in the centre of the pond. With this physically removed, the infiltration rate increased to 30 mm/day during the second monsoon, with no reduction in rate as the pond emptied.

5. Discussion

Seasonal and annual variability in climate dictates that these types of study require long-term (5 – 10 years) monitoring so the results from this study should be regarded as initial findings to be consolidated through ongoing monitoring.

So what do the findings of this research tell us about the effectiveness of the recharge structures? The additional water that the recharge structures are contributing to the aquifer has been quantified and an indication of the distance to which the impacts can be seen have been estimated. A measure of the effectiveness of the recharge structures is how this additional recharge compares with the natural groundwater recharge across the whole of the study area. These factors have been compared in the table, and they show remarkably similar results despite the considerable differences in catchment area, rainfall (both quantity and distribution), geology and useage.

The equivalent depth (4.8 to 12 mm) of additional rainfall recharged represents only a small percentage (0.6 to 1.4%) of the available rainfall but is calculated to be a significant percentage increase to that recharged naturally. The severity and short duration of the torrential flow at the Bhanavas site resulted in over-topping the check dam and filling of all structures. The course nature of the sediments in this headwaters part of the catchment ensured rapid infiltration to replenish the aquifer but not completely due to historic over-extraction and unconstrained use of available water on an annual basis. At a larger scale, the streamflow is likely to have infiltrated further downstream, thus the water has been relocated to nearer where it falls with the added benefits of reduced the time available to evaporate and better control of sediment transport and hence erosion. The aquifer has ample available storage capacity to accept the additional recharge but use continues to exceed replenishment. Additionally, during the period monitored, rainfall was lower than average. The proportion contributed by the check dam to natural recharge will vary with not only quantity of rainfall (high, low or average) but also intensity. Once a recharge structure is full, the rate recharge will not be increased whilst distributed natural recharge can continue. It would seem to be logical that in below average rainfall years that a larger proportion of recharge would be contributed by recharge structures.

In contrast, the available storage at the other two sites constrains the amount of additional water that can be recharged. At Chikhalgaon, the combination of a low storativity aquifer, high rainfall and low groundwater usage result in rapid replenishment of the aquifer at the start of the monsoon season. Recharge induced by the check dams has short transit times in the aquifer before surfacing as baseflow further downstream.

6. Summary of recharge at the AGRAR research sites

	Karnampettai	**Bhanavas**	**Chikhalgaon**
Catchment area	1.41 km^2	11.83 km^2	0.79 km^2
Rainfall in recharge period. (long-term average)	728mm* (Average: 527 mm. at Sulur station)	441 mm (693 mm)	1,860 mm (Average: 1660 mm. Karmoli. 12 years)
Volume recharged by structures	14,600 m^3	56,200 m^3	9500 m^3 (effective)
Depth equivalent	10 mm (1.4% of rainfall)	4.8 mm (1.1% of rainfall)	12 mm (0.6% of rainfall)
Natural recharge as estimated by the AGRAR project	41 – 47 mm (Sy = 0.8 – 0.9%) c. 6% of rainfall	30 – 120 mm (Sy range 0.5 – 2%) c. 7-27% of rainfall	80 –100 mm c. 5% of rainfall
Natural recharge estimates by CGWB (4 – 8% of rainfall)	29 – 58 mm	18 – 35 mm	150 - 260 mm (Limited by available storage in aquifer)
Increase in recharge due to structures in relation to project estimates (artificial/natural)	c. 23%	c. 4 – 16% This does not allow for stream- bed infiltration that would have occurred with no structures	13%

* Rainfall at Sulur. April to December 2004.

Groundwater levels in the lower reaches of the streams studied quickly rise above the levels of the check dams and hence groundwater drains into and not out of the structures. Although the check dams have limited impact as recharge structures they appear to "moderate" the streamflow at the watershed scale and provide watering points for livestock for extended periods. Moreover, these artificial recharge measures are likely to become more effective if, as trends suggest, abstraction of groundwater increases. This will increase the available storage capacity in the aquifer, on a seasonal basis, for replenishment by both natural and managed aquifer recharge.

The proportional increase in recharge is greatest at the Karanampettai recharge structure. Although the aquifer has a low storativity, it has been exploited to the extent that average, and indeed exceptional, natural recharge is insufficient to fully replenish the aquifer on an annual basis. Water that is replenished is used in the subsequent growing season, the quantity of recharge determining the extent of cropping. Again, because of the low storativity and transmissivity, the recharge mound is constrained to the immediate downstream environs, to such an extent that the groundwater level rises to the level of the stream-bed, where it presumably discharges, and the effect persists throughout the year. Construction of additional check dams would appear to be called for but the evidence available suggests that the area is over-provided. In the period monitored, all of the stream-flow into the Karanampettai structure during the southwest monsoon was captured and around 70% of the northeast monsoon; that is around 80% of the overall stream-flow during 2004. A new structure constructed a few hundred metres downstream captured little water.

The small percentage (0.6 to 1.4%) of additional rainfall captured by the recharge structures suggests that there is scope for greatly increased managed aquifer recharge activities. However, the Karanampettai case study clearly demonstrates that all available water was captured, as does the Satlasana case study to a lesser extent, as little or no water flows out of the immediate watershed. The majority of rainfall is utilised in satisfying the soil moisture deficit, evapotranspiration and distributed recharge to the aquifer. This appears to be particularly well managed in the Satlasana area where the permeable soils of the level field are bunded to promote infiltration of rainwater and minimise channelling and hence soil erosion. Only in the Kolwan Valley study was surplus water available on an annual basis due to higher rainfall and the limited storage capacity in the aquifer. Only in exceptional years will the current density of structures be used to capacity. It may be argued that this capacity should be available to capture these exceptional events but insufficient cost-benefit data were able to be collected in the short time of this study to be able to comment further.

Although the research adds value to current debates around the role of MAR, the study's limitations need to be highlighted. Specifically, detailed monitoring was carried out in only three locations and over two monsoon seasons; the project was too limited in time and scale to assess the long term impacts of MAR across a range of different physical and socio-economic environments. At the same time, the findings provided reasonably good insights on what happens to the water from artificial recharge structures, especially highlighting the variability in the processes that take place as a result of MAR, across different environments.

MAR is part of the groundwater manager's toolkit, which may be useful for replenishing depleted aquifers, controlling saline intrusion or land subsidence as well as improving water quality through filtration and chemical and biological processes. On its own it is not a cure for over-exploited aquifers, and can merely enhance volumes of groundwater abstracted. However it may play an important role as part of a package of measures to control abstraction and restore the groundwater balance.

Reference

Gale et al., 2006. Managed Aquifer Recharge: an assessment of its role and effectiveness in watershed management. British Geological Survey Commissioned Report CR/06/107N. Available at **http://www.iah.org/recharge/projects.html#AGRAR**

Artificial recharge to groundwater in an overdeveloped ewatershed – A case study of semi –arid region of Maharashtra , India

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1. INTRODUCTION

The case study is a part of the Tapi alluvial belt located within the typical Deccan traps of Maharashtra (India) which is categorized as an overexploited watershed (Figure 1). The study encompasses multidisciplinary investigations: analysis of existing recharge and water conservation structures, site selection and construction of new recharge structures and monitoring and impact analysis of the constructed structures over 2-6 years and the preparation of an artificial recharge plan of the watershed in a holistic way.

The study integrates the scientific knowledge of water, land, geology, topography and recharge techniques to suggest the best option for water management through conservation and augmentation in a particular setup by the most efficient and effective means. The study area is drained by the river Bhaunak, a northern bank tributary of the Tapi River and is therefore named as the Bhaunak watershed.

2. GENERAL FEATURES

There are 27 villages in the study area. The total population is around 58172 with around 11223 houses. The major part (70 %) of the area is cultivated land, followed by forest land (around 21%) in the elevation range of 300 to 1074 metres above mean sea level. There is stunning decline in the water table both during the pre and post – monsoon seasons and average decline of around 1 metre / year is recorded. A total of 3139 dugwells and 534 irrigation tubewells are abstracting the groundwater in the area (3833 electric pumps). Net groundwater recharge is around 20.2 MCM and gross abstraction is 26.3 MCM giving a stage of ground water development of 130 %.

3. PHYSIOGRAPHY & MORPHOMETRY

Morphometric analysis of the watershed has been carried out. The major drainage features of the watershed are parallel to sub-parallel. The watershed is elongated in the north-south direction. Streams of I^{st} and II^{nd} orders have bifurcation ratio around 5 indicating control of fractures / structures on some portion of the watershed. The sudden change in the course of streams suggests that these are controlled by lineaments. The II^{nd} and III^{rd} order stream basins have higher bifurcation ratio, indicating higher permeability of the soil media in the watershed. The value of drainage density indicates moderate to high permeability and relief in the watershed. The drainage length and slope of the drainages are essential input to work out the number of water conservation structures required in the mountainous terrain of the study area. Better geomorphological setup is available for favorable sites to store the surface runoff for augmenting the groundwater resources through artificial recharge, in areas above the median elevation i.e. 250 m amsl. Therefore, geomorphic setup is linked for the identification of favorable sites to store the surface runoff for augmenting the groundwater resources through artificial recharge.

4. CLIMATIC CHARACTERISTICS

Hydrometeorological analysis has been done to define the climatic characteristics of the study area. The watershed is semi-arid and partly drought prone. The rainfall is moderate and erratic. Rains are mainly received during the monsoon in the months of June to September. Rains occur in 40 to 80 days but in reality, effective rainfall beyond 10 mm / day takes place on 15 to 20 days only. Rain spells of more than 20 mm / day occur for around 5 to 10 days in a monsoon year. Rain hours are around 100 hours in the monsoon season in the study area. The daily rainfall analysis and the rainfall intensity analysis indicate that the roof top rainwater harvesting schemes may be designed as per the intensity of 50 mm / hour.

Weather parameters (temperature, wind velocity, relative humidity and sunshine hours) support the rising evaporation from February onwards. Therefore, evaporation parameter suggests that water storage in the open reservoir for artificial recharge to groundwater should be utilized before March. Surface water once transferred to the aquifer will get rid of the evaporation losses. The rainfall analysis suggests that a rainfall of 50 mm per day is appropriate to plan the water conservation in the hilly tract of the study area. The percolation tanks or other water storage / conservation structures can be designed for a rainfall of 698.5 mm arrived at 50 % dependability based on 100 years of rainfall analysis. Weather characteristics are therefore appropriately defined and incorporated in the design of structures.

5. SOIL CHARACTERISTICS

The texture of soils is coarser in the mountain front occupied by bazada formations. The soil moisture is less than five percent in the upper reaches. An infiltration rate of 20 - 30 cm / hour and more than 30 cm / hours is observed in the upper reaches along the foothill of Satpuda over the bazada formations. This tract is therefore, most suitable for percolation tanks. The soil properties clearly indicate that the impounding of water at the surface would not create any meaningful percolation in the alluvial plains therefore percolation tanks were not feasible for artificial recharge to ground water in the alluvial areas as compared to the foothill areas. Using an injection technique through wells or shafts would be a better option if soil texture is given a due weighting along with aquifer geometry in the alluvial terrain. Soil texture is therefore studied to identify the efficient technique and design of artificial recharge structures in the alluvial terrain.

6. HYDROLOGY AND SOURCE WATER AVAILABILITY

The detailed hydrological studies carried out in the area by continuous monitoring of percolation tanks and stream flows over the study period and its analysis has given a realistic estimate of catchment yield in different type of catchments. The catchment yield is the main input to design the storage capacity of the surface tanks. Runoff in the study area is estimated as 8.1% of the dependable rainfall (50%) against the 14.2 % estimated by using Strange's table. The status of water conservation is assessed as 4.15 MCM and around 9.187 MCM is let out to the Tapi River unconserved from the study area.

The mountainous streams flow for a considerable period consistently with silt-free clean water, which can be utilized as source for artificial recharge to ground, water by direct injection in the foothills itself. The available source water would result in maximum augmentation of groundwater if utilized at the highest possible part of the Bazada formations at the Satpuda foothills. This process will augment the aquifer water availability. The non-mountainous stream discharge is inconsistent and of relatively less duration though in large quantity. The presence of low to moderate siIt load suggests not to utilize this for direct injection to the aquifer as it will quickly clog the pervious part of the recharge structures.

The run-off relation for the mountainous terrain is arrived as the equation $\mathbf{Y = O.OO72\ X^{1.4106}}$ and for alluvial tract by the equation $\mathbf{Y = 0.028\ X^{1.1552}}$ derived from the study. This would result in assessing the realistic runoff assessment so as to enhance the capacity utilisation and economising the recharge operations. The quantum of water conserved is assessed as 4.15 Million cubic metre (MCM) while around 9.187 MCM is let out to the Tapi river unconserved from the study area. The streams flow period, whether consistent / occasional with silt free / silted discharge available, as a source for artificial recharge to groundwater suggests that different techniques must be utilised in the area.

7. GEOLOGICAL FEATURES

The study area is an alluvial terrain surrounded by the typical hard rock terrain of Deccan Traps. The general geological characteristics of the area are also remarkably different. The geology divides the study area into three prominent categories. The northern most part of the study area is occupied by the basaltic lava flows over around 50 Km^2. and is classified as consolidated or the hard rock terrain.

Talus and scree sediments commonly known as bazada occur at south of the basaltic lava flows occupying the foothills and are unconsolidated in nature (soft rock).

The third category of formation is unconsolidated alluvial sediments deposited as a layered sequence in a faulted basin. These sediments occupy around 60 % of the study area at a place having more than 300 metre thick alluvium and contain 12 distinct granular horizons separated by the clay beds. Contact of the basaltic flows and bazada is faulted as manifested by the common features of the faulting present in the fault zone. Hydrology and groundwater hydraulics is significantly influenced by the fault zone and bazada formations due to presence of porous strata at the surface and underneath.

8. HYDROGEOLOGY

Depth to water level is predominantly in the range of 30 – 40 metres bgl in the study area as per observations of year 2000. The historical data of water level are gathered from various sources. The record of year 1964 is the oldest database followed by the data of year 1975 (Figure 2). The water table was in the depth range of 10 – 15 mbgl in 1964 in the alluvial belt. Various tables, graphs and maps have been prepared to depict the periodical changes in the groundwater regime of the study area.

Comparison and analysis of depth to water level have proved the depletion of ground water level in the alluvial and bazada formations. There is overall decline of water table both during pre and post – monsoon seasons and maximum decline of around 1 metre / year as calculated for the period of 1990 – 2003. Seasonal fluctuations of water table were in the range 1-8 m and water table between 149 and 320 m amsl in the study area. Yield of dugwells vary between 100 – 200 M^3 /day and the discharges from tubewells were in the range of 0.5 to 90.2 M^3 / hour.

The hydrogeological framework and aquifer geometry decide the type of recharge structures and identify the location of sites. For this purpose detailed investigations and study of lithologs and well sections have been carried out. The surface spreading technique e.g. percolation tanks, cement plugs, basin spreading etc is not feasible in the alluvial tract due to unfavorable disposition of granular horizons and clay layers in the study area. Techniques like injection well and recharge shaft would be most feasible and appropriate based on hydrogeological setup. The hydrogeological framework of talus and scree deposits occurring at foothill of Satpuda provides favorable setup for artificial recharge through surface spreading and direct recharge techniques. Therefore construction of percolation tanks, recharge shafts and recharge pits is suggested in the bazada zone.

9. GROUNDWATER RECHARGE & AUGMENTATION POTENTIAL

Net groundwater recharge is around 20.21 MCM and gross abstraction is 26.25 MCM. The study area is overdeveloped up to the stage of 130 % and is categorised as an overexploited watershed. Aquifer parameters have been defined for shallow and deeper aquifer systems. The specific yield of the granular zones has been assessed as 15 % for the sand / gravel / boulder horizons and their admixture excluding the clay strata. Specific yield of the bazada formations is assessed as 10 %. Thickness of granular zones has been calculated based on the intensive analysis of lithologs and prevailing depth to water level in the study area. Average thickness of granular zones is 4.45 m to 18.85 m in the alluvium and 17.45 m in the bazada formations. There is a potential to store around 397 MCM of water in the unsaturated strata of the alluvial and bazada formations in the study area.

10. GROUNDWATER AUGMENTATION PLAN

This plan is derived by integration of the above information and knowledge and practical considerations like traditional water conservation practices and social acceptance and community participation. Ridge to valley concept has been incorporated to ensure the equity of benefits to all the areas. The technical feasibility and possible impact and benefits are also looked into the exercise (Figure 3).

Water conservation measures are planned for the hilly area which consist of 1545 nala bunds of average 1 m height and 6622 Km long continuous contour trenches (CCT) of 0.60 x 0.30 m cross section. It would indirectly increase the groundwater recharge in the bazada and alluvial aquifers. In the foothills, 2 percolation tanks and 12 recharge shafts are proposed for the artificial recharge to ground water. Further, gently sloping bazada tracts, require 3500 recharge pits of 7m x 7m x 3m dimensions to recharge the groundwater by utilising the rainwater. The alluvial tract is the most overexploited part of the study area and it is not possible to restore the groundwater storage within 15 years even after conserving the last drop of river runoff. Therefore, artificial recharge is proposed by utilising the external water resources may also be resorted to from the nearby canal provide ground water recharge to the tune of 20.69 MCM through 216 injection wells and 215 recharge shafts on annual basis.

Rooftop rainwater harvesting has been identified as important scheme of artificial recharge to augment the ground water resources around the villages of the study area so as to make the drinking water supply more sustainable and dependable in the summer season also. The rise in water table could be 0.5 to 1.0 metre in and around the village area; community participation is the key to ensuuring the success of such measures.

11. IMPACT ASSESSMENT

The area has net annual rainfall recharge of 20.2 MCM against the total annual draft of 26.248 MCM, with an annual overdraft of about 6.1 MCM of groundwater. Total artificial recharge to groundwater is estimated to be around 23.2 MCM as per the plan proposed in the present study. After implementing the proposed schemes, the overabstraction of 6.1 MCM would be taken care of and an additional groundwater pool of 17.2 MCM would be available to meet the rising demand of coming years. The declining trend of groundwater level would therefore be stopped and the rise in water level will take place @ 0.49 to 1.65 m per year in the granular zones.

Rooftop rainwater harvesting will be very useful to augment the groundwater resources around all the villages to make the drinking water supply more sustainable and dependable. The rise in water table could be realised specifically in and around the villages. Overall aquifer recharge may be managed to reduce the groundwater overdraft of 6.1 MCM through an additional groundwater recharge of 17.2 MCM. It would substantially meet the rising demand of water in coming years. The declining trend of groundwater level would therefore be reversed and the rise in water level could be up to @ 1.65 m per year in the granular zones. Water conservation measures are planned for the hilly area to indirectly increase the source water availability for ground water recharge. The alluvial tract is the most overexploited part and it will require more than 15 years even if the zero runoff is planned.

Figure 1.Index map of the study area

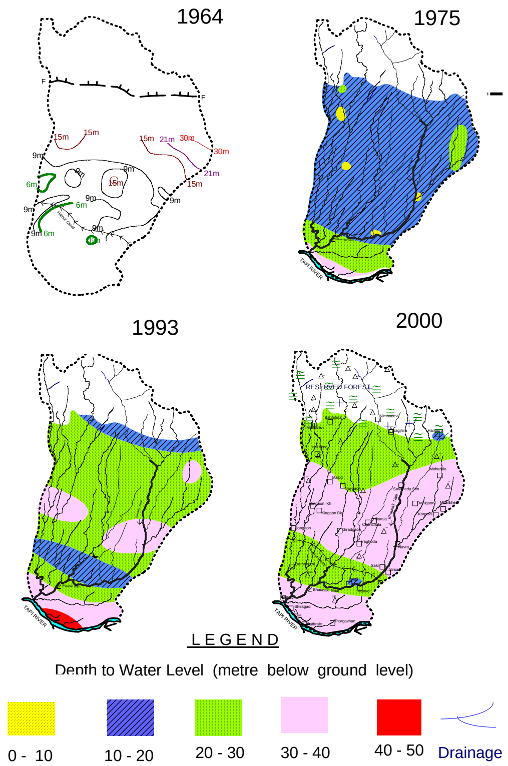

Figure 2 Chronology of pre-monsoon depth to water table in the study area – from 1964 – 2000

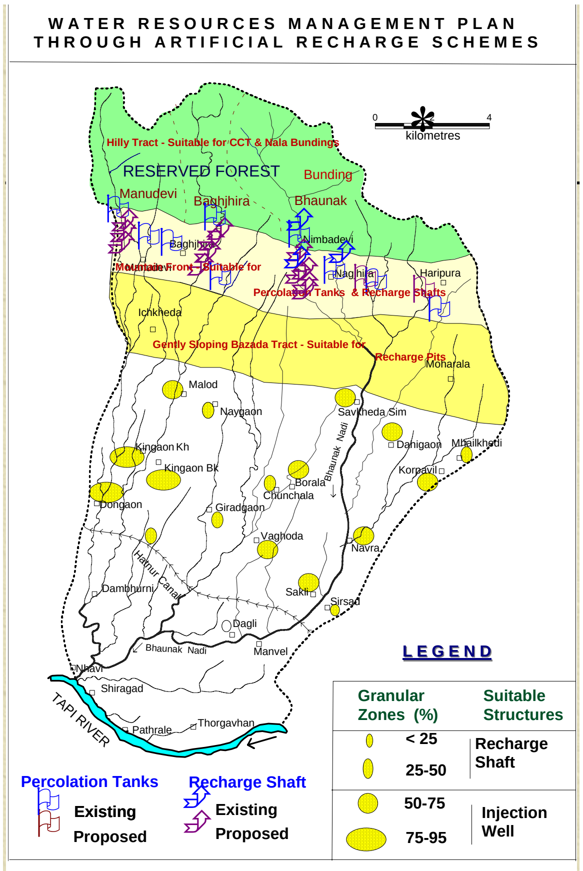

Figure 3 Water resources management plan through artificial recharge schemes

Water quality in the evaluation and effectiveness of RWH and MAR schemes– an overview

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Abstract

Rain water is a high purity resource but may easily become contaminated on storage unless correct procedures for collection and storage are made. Rainwater may provide the best source of domestic water in areas affected by salinity, high fluoride or areas affected by pollution from various sources. The quality of groundwater harvested naturally and augmented by small dams undergoes mineralization in accordance with the local geological conditions. The chemical and isotopic composition of the rain may be used as a tracer to identify the recharge pathways and, using chloride mass balance, it may be possible to quantify recharge efficiencies.

1. Introduction

Rainwater harvesting (RWH) is an ancient tradition in India (Pandey et al. 2003; Agarwal and Narain 1997) as well as in many other countries and under conditions of water stress is being "rediscovered" as a simple yet effective means of augmenting supplies. There is a growing network of NGO's, academics and Government institutions involved in both quantitative and qualitative aspects of RWH (see selected web sites below). Rainwater harvesting schemes are being introduced at the present day by non-governmental organisations as community projects. Many of these projects, which include direct harvesting and storage of rainwater as well as inducing recharge via small scale engineering structures, are shown empirically to be successful. However it is commonly difficult to demonstrate scientifically as well as economically the net benefits of water harvesting (Kumar et al 2006). There is a need for demonstration projects which analyse the overall hydrological impacts at a basin scale on surface and groundwater as well as the social and economic benefits. Water quality is often a secondary consideration in RWH schemes most of which concentrate on maximising the efficiency of water capture and storage.

The various water quality aspects relating to rainwater harvesting are summarised in Figure 1. Under natural conditions rain enters the soil, recharges groundwater or runs off as surface water over natural surfaces. During this process uptake of solutes and nutrients takes place which impart a distinct mineralisation to the surface or groundwater. Rainwater is slightly acidic and low or very low in dissolved solids, but on entering the soil rapidly takes up carbon dioxide from microbiological processes aiding mineral dissolution and, if carbonate minerals are present, the water will become near-neutral buffered by the carbonate-bicarbonate system.

The direct interception of rainwater for example by way of roof catchments or tanks bypasses the natural mineralising process and although water of good quality may be less acceptable for drinking purposes due to the absence of any mineralization or due to contamination on storage. The harvesting of rainwater in artificial or managed aquifer recharge schemes has many of the quality advantages of natural processes, providing contamination can be avoided.

The objective of this paper is to focus on the water quality aspects of rainwater harvesting, especially in rural situations. Rainwater harvesting is considered here as a low technology intervention although there is growing commercial interest in RWH systems applying state of the art technology. The natural quality of groundwater is first considered since water harvesting can often provide water of good quality in areas affected by salinity or other poor quality groundwater. Similarly, in areas affected by pollution from various sources, the harvested water may provide an improved and safer supply. The paper will also look at the use of environmental chemical and isotopic tracers, which may help to demonstrate recharge pathways of recent rainwater recharge and also confirm the efficiency of managed recharge schemes. The quality problems associated with collection and storage of rainwater are also reviewed.

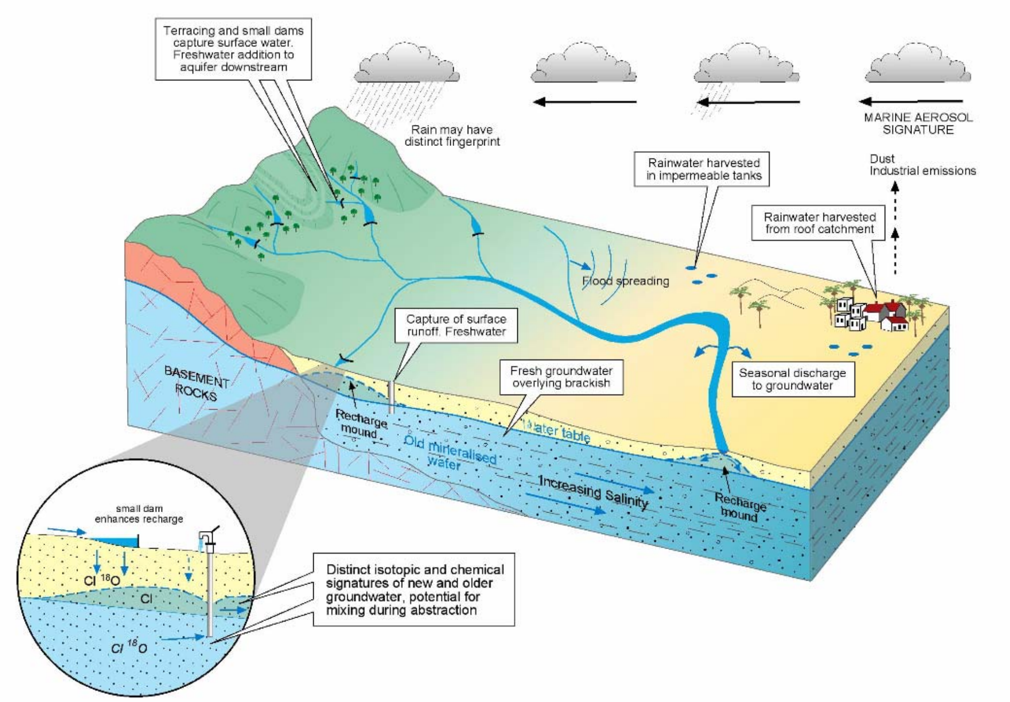

Figure 1 Water harvesting and water quality

2. Rain water quality

The initial rain water chemical signature is derived from the source of water vapour, primarily the oceans, and contains solutes entrained as marine aerosols, atmospheric dust and any impacts of human activity such as forest fires or industrial emissions (Goni et al 2001). Coastal rainwater may be high in marine aerosols but as the water vapour moves inland the residual vapour and rainfall will become purer. Meera and Ahammed (2006) reviewed the quality of harvested rain from several developing countries and show that the quality of harvested water often does not meet the drinking-water guideline values. Most of the studies reveal that harvested water is heavily contaminated microbiologically by a variety of indicator and pathogenic organisms unless special care is taken during collection and storage of rainwater. Heavy metals and trace organics may also pose problems in some cases.

3. Water quality of recharge to groundwater

Groundwater recharge takes place naturally in different ways, dependent on the soil, vegetation cover and geology. Diffuse recharge, across the whole landscape in permeable terrain takes place with rainfall above 200mm yr^{-1} (ref) but at lower mean annual rainfall recharge will usually be insignificant (Scanlon et al. 2006. Natural rates of movement from diffuse recharge will vary from a few mm/yr to up to one metre per year in sands, sandstones and similar porous media. Most of the uptake of solutes by infiltrating water takes place in the unsaturated zone as a result of weathering reactions which neutralise acidity and where mineral dissolution is enhanced as a result of the high soil pCO_2 concentrations (Appelo and Postma 2005). The net result is that the main properties of the water quality are determined in the top few metres.

Natural recharge take place more readily via fractured rocks (at least to shallow depths and recharge may be focused along faults, joint fractures or other geological lineaments, which may also determine overall drainage patterns. Artificial recharge structures exploit the greater permeabilities in gullies and valleys where infiltration initially may be rapid, but slower where silting occurs. The quality of artificially recharged water will therefore be superimposed on the natural baseline water quality which may not differ from natural recharge. In semi-arid regions however the baseline quality needs to be assessed, since relatively fresh modern water from artificial recharge may be superimposed on a baseline of older water containing, for example, higher salinity or high fluoride.

4. Tracer based approaches to measuring recharge efficiencies and timescales

The impact of rainwater harvesting can often be demonstrated visually or qualitatively but is more difficult to quantify. Above all, each site is different geologically and has surface properties including amount of silting, vegetation as well as a specific construction. Quantitative studies require observation sites, such as piezometers adjacent to structures and monitoring programmes over one or more seasons and are therefore labour intensive and costly.

The chemistry contains information that may help to demonstrate recharge efficiencies semi-quantitatively. The simplest approach is to use the chloride mass balance (CMB) where the increased salinity (chloride) is proportional to the amount of evapotranspiration and inversely proportional to the amount of recharge (R):

$$R = P.Cp/Cgw$$

For a quantitative assessment the amount (P) and chemistry of the rain (Cp) must be known and the chemistry of the infiltrating water must be measured. This has been applied successfully in many semi-arid regions (Scanlon et al. 2006) using unsaturated zone profiles, where surface runoff is near-zero. Including surface waters groundwater samples in the CMB approach is more complex but if the sources of Cl are known, an inventory of water inputs and outputs from the catchment (watershed) may be drawn up and the overall efficiency of the recharge scheme should be related to an overall decrease in Cl. This approach has been used by Sharda et al. (2006) in Gujarat, India in conjunction with measurements of the water table fluctuation (WTF). An increase in the water table correlated reasonably with a decrease in Cl over two research catchments covering an area of $812 km^2$. There is scope for further application of the CMB to estimating efficiency of RWH schemes providing appropriate data are collected including that for baseline conditions.

Stable isotopes of oxygen and hydrogen have potential as tracers in evaluating RWH. Rain storms often have distinctive isotopic signatures related to the trajectory of the air mass from the oceanic source and modifications taking place in the residual vapour as "rainout" occurs (Clark and Fritz 1998). Individual monsoon events may thus have distinct fingerprints that may be traceable into the aquifer. New storms may then be distinguishable from previous season's rainfall which may have undergone evaporation and enrichment in the heavier oxygen isotope (^{18}O). This approach needs testing on research catchments but should lead to better understanding of the recharge efficiency in a well characterised watershed, especially if tested with CMB and WTF methods.

5. Case study – fluoride endemic areas in Rajasthan

Several regions of the world have endemic health problems related to groundwater fluoride excess including the active alkaline volcanic province of the East African Rift Valley and other geothermal areas, ancient crystalline basement rocks of large parts of India, Sri Lanka and Africa and some sedimentary aquifers; many of these are found in arid and semi-arid settings (Edmunds and Smedley 2005). Basement aquifers in large parts of India and Sri Lanka (Dissanayake, 1991) are known to suffer from severe fluoride and fluorosis problems. In India, the worst-affected states are Rajasthan, Andhra Pradesh, Uttar Pradesh, Tamil Nadu and Karnataka (Handa, 1975; Suma Latha et al., 1999).

Handa (1975) recognised Rajasthan as the Indian state most seriously affected by high fluoride, with many accounts of the incidence of dental and skeletal fluorosis in the province. The distribution of fluoride in Rajasthan (11 districts) was also reviewed by Gupta et al. (1993). Studies in Sirohi district (one of the administrative districts of Rajasthan) seem typical of the rather complex geology of the region (Maithani et al., 1998) and illustrate the patchy nature of the fluoride occurrence (Figure 2). In Sirohi district, fluoride concentrations up to $16 mg L^{-1}$ have been found in groundwater from dug wells and boreholes at depths between 25–75 m (Maithani et al., 1998). A good correlation of fluoride with the bedrock geology is observed, with highest concentrations being found in association with the granites, acid volcanic rocks and basic dykes (Figure 2). These dykes act as barriers, which slow down groundwater flow and permit prolonged contact times to raise concentrations of groundwater fluoride. Low-fluoride areas in the east (<1.5 mg L^{-1}) are associated with carbonate rocks and higher calcium may inhibit an excess of fluoride.

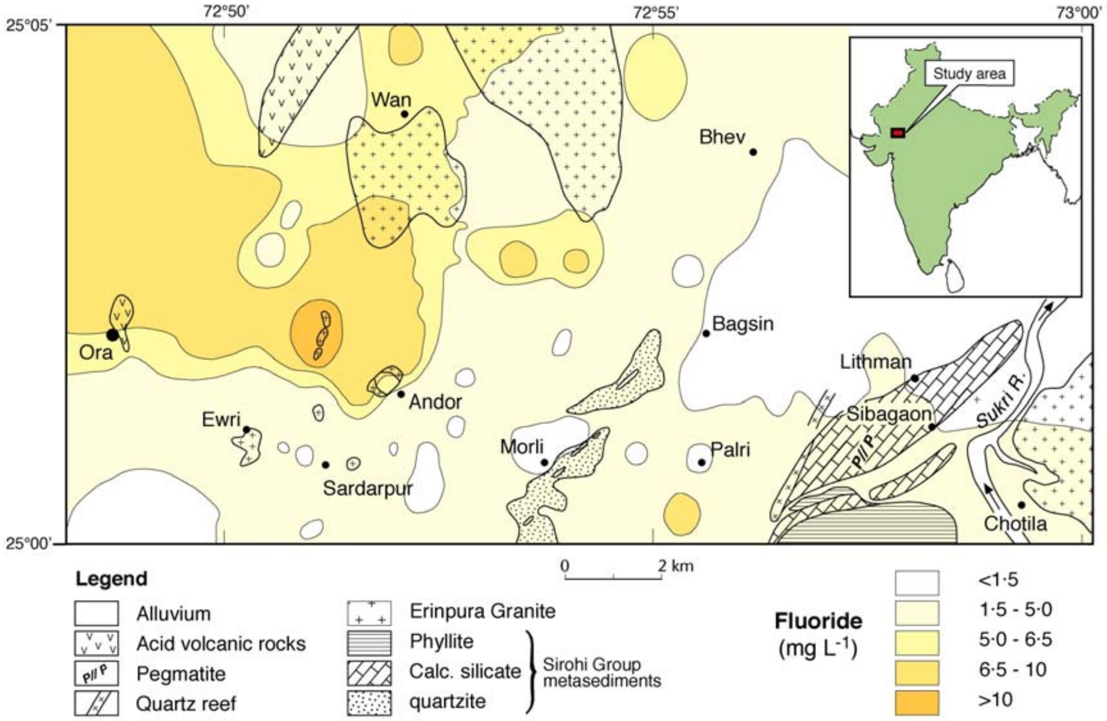

Figure 2. Geological control over fluoride occurrence – Gujarat. From Maithani et al. (1998)

This study first shows that in low-rainfall areas with potential fluoride problems such as Rajasthan, it is important to assess the hydrogeological situation very carefully. The generation of high-fluoride groundwaters usually requires considerable residence times in the aquifer. Thus, it is likely that younger, shallow groundwaters, for example those recharged rapidly through check dams and stream channels, may have low fluoride concentrations compared with older groundwater. They may be exploitable by skimming the shallow water table rather than abstraction from deeper penetrating boreholes which mix water of different quality.

High fluoride waters have traditionally been treated by a range of techniques including precipitation/flocculation, adsorption/ion exchange, use of alum (Nalgonda technique) adding Ca through gypsum, calcite, calcium chloride, activated alumina, activated carbon, ion-exchange resins, clay pots, crushed bone, bone char.. However most methods designed for village-scale fluoride removal have drawbacks in terms of removal efficiency, cost, ethical issues, local availability of materials, chemistry of resultant treated water and disposal of treatment chemicals as well as monitoring the process. The harvesting of rainwater, either directly in cisterns, tanks or by careful collection via small recharge dams, offers a potentially safe and attractive alternative solution in endemic areas.

6. Rainwater collection and storage

Water quality issues associated with rain water collection and storage have been reviewed by Ashworth (2005) and Meera and Ahammed (2006). Most publications relate to urban and developed countries and there is a need for more studies in developing countries. Studies show that microbiological quality is often better than shallow groundwater (Meera and Ahammed 2006) - in WHO “low risk” category. The main factors relating to construction and to the types of quality problem may be summarised.

Materials and construction and related factors

(i) Roof material – the chemical characteristics, roughness, surface coating, weatherability need to be considered as suitable for collection. Rough surfaces are more prone to contamination.

(ii) Roof location – the avoidance of trees, proximity to any emissions from domestic or contaminant sources need to be considered in siting structures

(iii) Deposited matter (mineral, organic, biological) on the roof. The roof is likely to be collector for dead insects, birds as well as vegetation. Avoidance of the initial rains and fitting of first flush devices such as leaf slides.

(iv) Anaerobic decomposition may take place in down pipes or small storage tanks unless avoided as in (iii) above. Problems can be avoided by proper siting, use of large tanks or use of a settling tank.

Chemical and Microbial quality and related factors

(i) Many studies (from developed countries) report variously - bacterial diarrhoeas, bacterial pneumonia, botulism, protozoal diarrhea, *Giardia* and *Cryptosporidium.* Dry heat will however kill most organisms.

(ii) Studies show that faecal coliforms, total coliforms, faecal streptococci decline rapidly on storage, especially if larger tanks are used, although certain strains *Pseudomonas* and *Aeromonas* can still grow during storage.

(iii) Open storage structures in hot countries may become attractive for mosqitos and other insects and a protective mesh or seal must be used.

(iv) Natural rain water may be acidic but pH usually rises during storage especially if cements used in construction. Some acidity may also be produced on breakdown of organic matter Remnant acidity may mobilise metals (Zn, Cd and Pb) from roof materials.

(v) Trace organics – PAH (polycyclic aromatic hydrocarbons) are frequently adsorbed with clay tiles in urban areas – probably the by products of fuel burning. Pesticides are also found in roof runoff in some rural areas.

(vi) There may be problems in public perception and water quality, especially if communities are used to more mineralised groundwater for example. At household level the main problems will be the presence of leaves and other solids, presence of mosquitos and other insects as well as residual colour or taste.

7. Conclusions

Rainwater collected and stored correctly can offer an additional high quality resource at household or small community level. Understanding the various factors affecting quality can help to maintain purity of the resource. Rainwater chemistry will vary from place to place and be influenced by proximity to the oceans, dust and aerosols derived from human activities such as fuel and forest fires. Attention to roof and other collecting surfaces, suitable collection and storage procedures will minimise contamination from pathogens, excess organic material (leading to anaerobic conditions) as well as organic chemicals; discarding the first flush is recommended.

Rainwater capture by check dams and other small structures leads to the infiltration of generally high quality water which may create a seasonal freshwater mound above the regional water table. This water undergoes water-rock interaction in the same way as natural recharge and becomes slightly mineralised, according to the geology. This freshwater may become an important domestic resource along with roof water harvesting in areas affected by high salinity or high fluoride groundwater. The harvested rainwater acts as a means of raising regional water tables. The chemical and isotopic signatures in the water may be used to measure recharge pathways and in favourable circumstances. to quantify recharge

References

Agarwal, A., Narain, S. 1997. Dying wisdom. The fall and potential of India's traditional water harvesting systems. Centre for Science and Environment. Delhi

Appelo CAJ and Postma D. 2005. Geochemistry groundwater and pollution. Balkema

Ariyanada T. Quality of collected rainwater from Sri Lanka.

Ashworth, J. 2005. Roof collection and storage of water for drinking. Proc. Inst. Civ. Engnrs: Water Mangement 158, 183-189.

Clark L and Fritz P. 1997. Environmental Isotopes in Hydrogeology

Dissanayake C. B. 1991. The fluoride problem in the groundwater of Sri Lanka - environmental management and health. *International Journal of Environmental Studies* 38, 137-156.

Edmunds W M and Smedley P. 2005. Fluorine in natural waters – occurrence, controls and health aspects. pp 301-329 in Essentials of Medical Geology. Eds O. Selnius, B. Alloway, J.A. Centeno, R.B.Finkleman, R.Fuge, U. Lindh, P. Smedley. Academic Press

Frasier G W. 1983 Water quality from rainwater harvesting systems. J Env Qual 12:225-231.

Handa B. K. 1975. Geochemistry and genesis of fluoride-containing ground waters in India. *Ground Water* 13, 275-281

Kumar, M.D., Ghosh, S., Patel, A., Singh, O.P. and Ravindranath, R. 2006. Rainwater harvesting in India: some critical issues for basin planning and research. Land use and Water Resources Research, 6, 1-17.

Meera, V. and Mansoor Ahammed, M. 2006. Water quality of rooftop rainwater harvesting systems: a review. Journal of Water Supply: Research and Technology – Aqua 55, 257-268.

Maithani P. B., Gurjar R., Banerjee R., Balaji B. K., Ramachandran S., and Singh R. 1998. Anomalous fluoride in groundwater from western part of Sirohi district, Rajasthan, and its crippling effects on human health. *Current Science* 74(9), 773-777.

Pandey D N, Gupta, A K and Anderson D M. 2003. Rainwater harvesting as an adaptation to climate change. Current Science, 85, 46-59.

Scanlon, B R., Keese, K. E., Flint, A.L., Flint, L.E., Gaye, C.B., Edmunds, W.M. & Simmers, I. 2006. Global synthesis of groundwater recharge in semi-arid and arid regions. Hydrological Processes, 20, 3335-3370.

Sharda V N, Kurothe R S, Sena D R, Pande V C. and Tiwari S P. 2006. Estimation of groundwater recharge from water storage structures in a semi-arid climate of India. Journal of Hydrology, 329, 224-243.

Suma Latha S., Anbika S. R., and Prasad S. J. 1999. Fluoride contamination status of groundwater in Karnataka. *Current Science* 76(6), 730-734.

Web sites

www.environment-agency.gov.uk/subjects/waterres/286587/511050/

http://www.rainwaterharvesting.com/ Sri Lanka

http://www.eng.warwick.ac.uk/dtu/pubs/rwh.html Warwick University

www.webasia.com/rainwaterharvesting/pubs/prs Sri Lanka and Asia Network

http://www.lboro.ac.uk/garnet/tncrain.html

http://www.twdb.state.tx.us/publications/reports/RainwaterHarvestingManual_3rdedition.pdf

The Potentials and Impacts of Water Harvesting Projects in Arid and Semi-Arid Regions (based on lessons learnt from some Implemented cases in Iran)

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1. Introduction

Rainwater Harvesting is a popular term used for a tradition of collecting rainwater, improved by modern concepts and technologies, a result of more than two decades of research work around the globe. Effective management of rainwater harvesting and aquifer recharge is becoming an increasingly important aspect of water resources management strategies. Growing earth population over the last few decades and the advent of submersible pumps resulted in over utilizing the storage capacity of aquifers, with, to the extent that many aquifers are now being exploited at rates far in excess of natural recharge. Rainwater harvesting as one component of a watershed management strategy can only succeed if used in conjunction with demand management appropriate for the socio-economic setting.

Project evaluation is a means of investigation and of reasoning to assist decision-makers, private and public sectors alike, in their efforts to make informed and reasonable decisions. In its broad sense, evaluation is the process of identification and quantification of possible or expected impacts from one or a series of given activi(es) where some of the impacts are regarded as benefits while others are costs. In studying the conditions of rainwater harvesting, evaluation will play a key role in better understanding their potentials, weaknesses and the factors involved. Once these have been fully identified, then improved and friendly use of the resources will become possible.

This paper examines the potentials, and effectiveness of rainwater harvesting projects in arid and semi-arid areas based on lessens learned from some of the implemented cases in Iran. Commonly used methods in hilly and flat land include practices in macro and micro catchments for a variety of purposes such as drinking and household water supply, irrigation, navigation and, water foul and fish culture have studied. The study shows that high rain which falls in wet years in arid and semi-arid regions is more than 2.5 times of average figure and 6.4 times more than that of dry years and can be harvested and utilized during dry periods. Rainwater harvesting is also an inexpensive means of water mitigation and results in large return for relatively small investment. All the implemented cases provide important benefits by recharging the aquifers and increasing farmer income, reducing drought and flood damages and raising people's incomes. The results obtained indicate that rainwater harvesting is an easy and economic method of water utilization in the arid and semi-arid regions with average benefit-cost ratio of 8 in studied cases (from a minimum of 1 to maximum 150). The highlights of the system are simple technology and ease of construction which encourage community to participate in extension of these practices.

2. Regional setting

Iran is located under a subtropical high-pressure belt with typically arid and semi-arid climates. The two mountain ranges, the Alborz extending along the north and the Zagross stretching along the northwest to southeast, have created a variety of climates as well as different geomorphologic features such as coastal plains, salt lands in central Iran, semi-desert steppe, and desert areas. It is characteristic of arid and semi-arid zones to have their precipitation typically fall during a few days with no precipitation over long periods following each event. As a result of instable climatic conditions such as temporally uneven rainfall distribution or great differences in diurnal and nocturnal temperatures, these areas normally lack suitable and satisfactory vegetative cover and their soil texture is normally erodible and fragile resulting in flooding after any flash rain event that washes away subsoil on mountain slopes, giving rise to severe water erosion in mountainous areas and, finally, to wind erosion in desert areas.

Temporal and spatial distributions of precipitation in Iran are totally variable and non-uniform. Relatively 52% of the annual rain and snow fall over only 25% of the country such that 90% of the total precipitation falls during the cold wet seasons and in the northern and western areas leaving only 10% for the central, eastern and southern areas during hot and dry seasons. Water scarcity is sure to cause crises for certain areas in near future. In addition to these environmental problems, uninformed decisions and interventions only augment the damages, warranting more serious and careful land management under such sensitive and delicate environmental conditions. Two natural events, namely, floods and droughts cause vast damages to the national economy each year.

Supplying for various water demands including drinking, agricultural, and industrial water, is inevitable but this must be accomplished only with appropriate provisions to protect the environment and its renewable natural resources in addition to prevention of further desertification. No doubt, the sustainability of efficient methods of resource protection and development relies not only on observation of scientific standards and employment of time and space specific methods but also on the full participation of the public and other parties involved. In an age when water is regarded as a global political tool and as one of the most important instruments of development and while we have a long history of wars over water, it seems inevitable and reasonably clear that we must adopt efficient means and measures to achieve our multipurpose development goals at minimum time and effort with the least damage to the environment. In arid and semi-arid zones where precipitation is quite small with uneven distribution, a large volume of the resulting flow leaves our access in the form of runoff or destructive floods. Water, under these conditions, will act as the most important limiting factor in development when it is scarce and as the most destructive and damaging factor when it flows as seasonal and transient floods.

3. Potential Surface Water Resources

Iran is a vast country that unfortunately struggles hard with water scarcity due to its special location in a (semi-) arid zone such that of the total 35 million hectares of its arable land, only around half (i.e. 18 million hectares) can be cultivated from which 10 million hectares is dry farmed. It follows then that the major limitation in the agriculture sector is that of water shortage. It is unfortunate that despite this water shortage we are not usefully utilizing the existing water resources as we should so that a great portion of our water is lost to improper and uninformed water management.

Table 1 Division of harvestable water resources by the 2020 horizon across the country according to different resource types in Billion Cubic Meters

The hydrologic balance has been computed for a 30-year period according to the basic meteorological, groundwater, and agriculture data available. Table (?) presents the results of these computations for each of the 2nd grade watersheds as divided into mountainous and plain areas. The Table shows that the average surface flows over a 30-year period amounts to 94 Billion cubic meters. It need be mentioned that this quantity may undergo drastic fluctuations in dry and wet years.

4. Estimation of Surface Flow Volumes

Surface flow analysis

The data from 1098 hydrometric stations across the country were analyzed to determine the potential harvestable water. The summary of the analysis is presented in the Diagram. According to this study, the potential water from water resources in wet years will be greater than 260 MCM.

30-year rainfall analysis

The results from this survey show that from among 646 sub-catchments studied over the 30-year statistical period, the percentage of rainy days was less than 10% in 161 sub-catchments, 10%-20% in 136 sub-catchments, 20%-30% in 74 sub-catchments, and higher than 30% in 90 sub-catchments. The total regional precipitation was found to be 594 billion cubic meters averaged over the 30-year period and 164 billion cubic meters as the minimum over the same period while the total precipitation as the maximum of the 30-year period for the region was equal to 1178 billion cubic meters. The survey also indicated that the potential yield of water resources in wet years is higher than 228 MCM.

Table 2 Division of water balance across the country under various conditions in billion cubic meters

5. Groundwater balance

In order to estimate groundwater balance in each of the grade 3 watersheds across the country, the watershed was subdivided into study areas typically in the form of a plain containing one groundwater resource and then the water balance components were computed. The groundwater balance components were computed for each of the hard formation reservoirs, heights, and alluvial aquifers in each study area independently. The results show that over the study period, the average annual groundwater was approximately 0.060 negative amounting to 5 billion cubic meters (Report on Critical Plains and Regions (In Persian), Namab, Ministry of Energy, 1995).

Table 3 Surface and ground water shares in supplying for the state water demand (figures in billion cubic meters)

6. Watershed Management and Aquifer Management

Watershed management involves the identification, planning, policy-making, and adoption of a set of measures and activities to conserve and reclaim basic resources with reasonable exploitation of the natural resources in a watershed without adverse impacts on the natural environment. It is essential in watershed management to consider and to take account of all economic, social, cultural, and institutional factors involved in the watershed as well as the external factors affecting the interactions within the watershed with due consideration to the nature of the ecosystem in the watershed.

The enhancement of the vegetative cover (natural forest, range, or farm plants) and the resulting improvement of the livelihood of the local community (farmers, livestock breeders, and users of the forest and rangeland by-products) is one of the corollary impacts of soil and water conservation and the increased soil moisture. In other words, it may be concluded that watershed management activities are multi-purpose activities that are cost-effective and economical while their execution calls for very simple and low cost technologies that can be easily implemented and scaled up by local communities.

Given that watershed management activities aim at soil and water conservation and at stabilization of plant growths (natural forest, range, or farm plants), it follows that such activities automatically lead to the conservation of (both plant and animal) biodiversity while also preventing the loss of soil fertility through maintaining soil nutrient and organic contents (i.e., desertification control). Maintenance and propagation of plants will, on the one hand, increase photosynthetic activity and, consequently, will stabilize carbon and control greenhouse effects (combating climate change), and, on the other hand, will conserve soil (wind and water erosion control) through preventing the beating of raindrops on soil particles, which will additionally reinforce soil by plant roots to increase their resistance (through plant stems and crown) against water flows or wind blows.

On top of all this, utilization of floodwater is regarded as one of the most important solutions to the problem of shortage of fresh and agricultural water. At the mountain outlets in watersheds, there are normally vast areas of coarse grain sediments where floodwater can be stored and used to enhance agricultural productivity and sustainable development and to reclaim natural resources. Besides the natural conditions of land and precipitation, the main reason for this lies in reduced evaporation losses and the huge potentials it yields for agricultural development in arid and semi-arid zones. One of the most effective methods of increasing the potentials of water resources is flood spreading over alluvial fans and plains containing coarse grain sediments which enhance agricultural production as well as forest and range reclamation. It is, therefore, essential to identify such areas and to adopt the most efficient and locally appropriate methods for their exploitation.

6.1 Evaluation of the potentials in watershed management and aquifer management

Evaporation is responsible for 70%, or around 270 billion cubic meters, of precipitation losses in water supply systems. If we assume that solar energy and insolation can potentially vaporize an average of 2500 mm of precipitation per unit of area, it is then expected that the evaporation capacity will be greater than 4125 billion cubic meters (that is, if enough water is available to evaporate). In other words, assuming a uniform distribution across the country, 120 billion cubic meters of renewable water can be vaporized back into the atmosphere in only 10 days. The only reason why this does not normally happen is that the water does not find the time to evaporate as it is trapped under ground in aquifers or in mountains where far less evaporation takes place. Thus, if the total precipitation across Iran (i.e., 413 billion cubic meters in dry years and 1037 billion cubic meters in wet years) is denied a chance to evaporate, then it can be stored in aquifers under the ground (away from direct evaporation) to be used when needed. The question that arises at this point is whether there are enough natural reservoirs to store this quantity of precipitation. A brief investigation should reveal that over 50% of the country is mountainous with very low evaporation capacity and with coarse grain areas which provides the capability to store water and to delay subsurface flows. If we assume 5 rainfall events to occur annually and if only 1000 m^3 of water is infiltrated, then the whole precipitation in a wet year can be completely accommodated in the natural reservoirs. Additionally, there are over 14 million hectares of coarse grain alluvia with an average depth of 100 meters. If only 10% of the water storage capacity in these alluvial areas is filled with water, we will have a water volume of 1400 billion cubic meters, which is considerable (it suffices only to compare this figure with the total capacity of all man-made reservoirs, i.e. less than 35 billion cubic meters, to be constructed in the next ten years).

There are numerous problems associated with investment in new dam projects that deter investment in the face of natural recharge possibilities available. Evaporation rate in open reservoirs is rather high and they commonly face such as problems as sedimentation and pollution. Moreover, increasingly fewer suitable dam sites can be located for the construction of new dams while these sites typically pose many technical difficulties that are extremely expensive to overcome. The investment required for each cubic meter of water storage capacity in surface open reservoirs is nowadays 5 to 10 times higher than the capital investment formerly required for similar projects constructed in the past. Another aspect of these new projects is their estimated storage capacity that cannot be justified in the face of greatly fluctuating annual precipitation. Even using data and information from previous projects cannot resolve the problems in most cases. This is while estimating water storage capacity as watershed management or aquifer management activities is not only a unique solution but can also be accomplished with only 20% of the costs in other projects. Furthermore, no investment will be required for new water transmission system development or for dam site development since such operations when needed may be accomplished in the vicinity of the natural resource sites which now amount to over 5,000,000 in Iran.

7. Economic evaluation of watershed management activities

7.1 Objectives and Scope

The main objective of the present survey is to present economic indices computed for some of the projects under execution in the watershed management sector from which adequate information has become available. The detailed objectives of the economic studies presented in this report include:

- Examination and finalization of the economic data received and preparation of equivalent and classified basic data based on study phase with which the computation of economic indices can be initiated.

The scope of these studies involves investigations on the basis of quantified (in Rials) project impact criteria accomplished within the framework of engineering economics principles. In other words, except for economic criteria, other criteria (e.g., stability and security, economic self-sufficiency, economy of scale) are not included in this report.

7.2 Methodology and Fundamentals

In the present survey, benefits and costs of different projects from the viewpoint of the society as a whole will be investigated using the social benefit/cost analysis. This analysis requires an analysis and evaluation of all possible economic opportunities gained and lost. However, due to time and space limitations, the impacts used in this survey include only those that are quantifiable, that can be expressed in monetary value, that have a direct bearing on production or economy, and those that are related with economic development objectives. The factors in view for this project impact analysis involve national economy, the parties involved, participants, and users of the project. The items in the benefit/cost analysis have been quantified and valued according to market prices assuming that the prices represent the social value of the costs and benefits.

7.3 Interest indices

The indices used for the comparison of projects in this report include:

- Internal Rate of Return
- Net annual present value (B-C)
- Profitability ratio (N/K)

In the light of what went above, the projects surveyed are classified along the following lines:

7.4 Computation method

In order to compute the above economic indices, the annual costs of each project were initially computed using the annual equation. The costs obtained were then compared with annual benefits and the following classification was obtained:

- *Unacceptable projects*: Projects that show an IRR of below 6% (the cost of investment opportunity under the main conditions of the original survey), a negative net value, and a profitability rate of lower than unity.
- *Acceptable projects*: Projects that show an IRR of above 6%, a positive net value, and profitability rate of above unity. These projects were also sub-classified into projects *nearly justified* and projects *fully justified*. The former have an IRR of between 6 to 8%, a net value of 0 to 1500 million Rials, and a profitability rate of 1.1 to 1.3. Projects with economic indices higher than these values were classified as fully justified.

7.5 Valuation and pricing

Valuation and pricing of project impacts were based on the pricelists of the fiscal 2006.

7.6 Policy analysis

To compensate for the uncertainties and approximations in estimating project costs and benefits, the following items have also been taken into account in this report:

7.7 Interest rates

As no prices have as of yet been declared for use in the computation of economic indices for watershed management projects, the economic indices for the projects under survey have been presented with different interest rates of 0, 0.25, 0.5, 0.75, 1.0, 1.5, 2,, 3, 4, 5, 6, 7, 8, 9, 10, 12, 15, 18, 20, 25, 30, 35, 40, 45, and 50%.

7.8 Basic data

The basic data for cost and benefit estimations used in this survey are taken from independent technical-economic studies performed by different consulting engineers the accuracy of none of which ever goes beyond the accuracy of data provided by feasibility, phase I, or in rare cases phase II studies.

In order to obtain equivalent and similar data to be used in computing economic indices, the inadequacies in basic data were first identified. Then efforts were made to provide the missing data through the most readily accessible sources given the time limitation we had. But as indicated above, assumptions had to be replaced in certain cases for some of the missing data.

7.9 Costs

By "cost" is meant all the expenses and financial damages that are directly and indirectly incurred and borne by the executive body for the execution of the project and the accomplishment of project objectives. The expenses must be quantifiable in Rials and include initial capital investment, maintenance, and operation costs.

Since certain projects may follow double or multiple purposes, the investment costs are determined according to the benefits secured or accomplished for each purpose and it has been further assumed that (cash flow) cost distribution over the construction period is linear.

7.10 Benefits

The benefits of watershed management projects include benefits resulting from water directly harvested, from water harvested after recharge or infiltration, from erosion control, sedimentation control, or from animal feed produced, from agricultural production, and from flood damage control as measured by previous events.

7.11 Interest indices

Watershed management projects play a very delicate role in regulating the social life in Iran with regard to its climate conditions. Allocation of budgets and funding, comparison and selection of significant projects of reasonable variety are thus of great importance.

Over the past 40 years, watershed management activities have only been executed in around 10% of the watersheds in Iran. Comparison of the immediate needs and the facilities available indicates a wide gap between the large volume of investment required and the facilities available for the execution of watershed management projects. The employment of economic principles in prioritizing watershed management projects is, therefore, an important decision-making tool. This is mainly because investigation of the methods available for funding projects and for allocating the scarce facilities and economic resources should form the basic aim of any economic assessment.

7.12 Net benefit

The Table shows the economic indices of watershed management projects according to annual net profits in an ascending order. The net-profit-based prioritization of projects is similar to prioritization on IRR.

7.13 Profitability ratio

Prioritization of projects is presented according to their profitability ratios in the Table for watershed management projects economic indices. It is evident from the Table that on the basis of this index, investment on most watershed management schemes is associated with a high level of reliability.

8. Survey of typical projects executed

In the Babgohar Watershed in Zaranad, Kerman, watershed management operations together with the construction of earth dams has increased the average discharge rate of 32 qanats and springs from 3.85 l/s to 7.2 l/s (around two times). In the same watershed, the construction of 48 earth dams, 6 rock-mortar dams, and 115 rock dams has resulted in the storage of one MCM of water during each rainfall event.

In the Panj Kouh Watershed, Kerman, 97 earth dams and 7000 cubic meters of mortar dams were constructed to store about one MCM of water during each rainfall event. The discharge rate from qanats and springs in the region also rose by 1.5 to 3 times as a result of these operations. The average discharge rates from 13 qanats were measured to be 12 l/s before the operations whereas after the operations the measurements showed discharge rates of 20 l/s.

In Zavir Watershed, Rafsanjan, the average discharge rate from 23 qanats and springs before watershed management operations was measured at 9.8 l/s while it increased to 19.2 l/s after the execution of the project.

8.1 Flood Control and Flood Spreading Project in Dalankouh, Fereidan

The execution of this project allowed for the recharge of 5 MCM of water annually. This recharge project not only prevented the further decline of the water table but also raised it by 3 meters.

8.2 Flood Control and Flood Spreading Project in Bagh Sorkh, Shahreza

The execution of this project stopped the groundwater drawdown trend in the plain and according to assessments in 1997-98, around 7.8 MCM was recharged into the water reservoir.

8.3 Flood Control and Flood Spreading Project in Sarasiab, Ardestan

This project in Sarasiab controlled over 830,000 m^3 of water to prevent flood-caused damages to the downstream town Arisman and Sarasiab Village. In the flash rain event on May 27, 2006, the resulting flood flow was completely controlled. This was while the land areas outside the project domain were inundated and damages worth of 30 billion Rials were inflicted on the facilities.

8.4 Urban Flood Control Project in Khansar

This project was executed to control floods in the urban Khansar area. The 117 mm rainfall event in 1987 led to a disastrous flood flow in the town which claimed 16 lives and left huge damages to property and urban facilities. After the execution of this project and the construction of 133 rock and mortar and gabion delay weirs, the town has become secure against flood flows. In the flash rain in 1998 (with a higher intensity than the 1987 event) no damages were reported.

8.5 Watershed Management Project in Balan Watershed, Naien

The purpose of this project in Naien was to combat droughts and to supply irrigation water. The measurements show that the discharge from qanats in the region has risen by 4 times, increasing cultivated land, improving irrigation, and lifting social problems.

8.6 Seasonal Flood Control in Nahoojan, Ardestan

The comparison of discharge rates before and after project execution revealed drastic impacts and considerable changes.

9. Evaluation of biomechanical projects

A. Construction of contour furrows in various towns in Isfahan Province has controlled over 95% of the runoff in urban areas;
B. Vegetative cover crown has risen from 6-10% to 50-60%;
C. With the increase in plant crown, soil erosion has decreased to one ton per hectare.

9.1 Assumptions in project economic assessment

1. The forage produced has no associated additional costs. The price for 1 kg of dry forage is assumed to be 650 Rials.
2. The crops (wheat and barley) produced were part of the planting, growth, and irrigation costs, irrigation accounting for 30% of the total costs. The water cost for 1 kg of wheat is assumed to be 400 Rials. The wheat produced is a by-product produced as a result of management of the watershed through such activities as plowing, furrowing, etc.
3. The analysis of investment return and the value of 1 m^3 of sediment trapped:
   The sediments are trapped by settling dams. It need be mentioned that erosion control entails sediment control, which has not been taken into account here. According to our surveys, the cost for building storage capacity in both large and small dams is estimated at 5,000 Rials per cubic meter. If we assume that one cubic meter of sediment enters dam reservoirs during each event, the amount of sediment replacing water in the dams will be at least the number of events by at least half the effective life of the dam. The loss for one cubic meter of sediment entering the dam would, then, be:

$$5,000 \times 1 \times 35 = 175,000 \text{ Rials}$$

This is only the cost of storage capacity-building neglecting such costs as maintenance of dams and downstream irrigation channels, or the costs required for new dam construction. It must also be remembered that there might be no other suitable site for new dams to be built in the region, which will have irreparable damage then. Thus, the economic benefits of sediment control projects are calculated along the following lines:

175,000× volume of sediment trapped = economic benefits in terms of water supplied

It must be noted again that one cubic meter of sediment entering a dam in the first year of operation will replace a volume of water equal to the product of its effective life in years and the number of events in one year. This is while the same amount of sediment entering the dam in the last year of operation will replace water only for one year.

The mean of these two figures will be equal to half the effective life of the dam which is 35 years. Now multiply this by 175,000 Rials to obtain the loss inflicted by one cubic meter of sediment in the dam, or equally the economic benefit ensuing from a sediment control project; hence, 175,000 Rials as the economic benefit of one cubic meter of sediment controlled.

4. Estimating the loss from one cubic meter of soil eroded:
According to Item 20503 of the pricelists released by Management & Planning Organization (construction pricelist for 2004), the cost for procurement, transportation, spreading, and leveling of any type of farm soil is 52,200 Rials per cubic meter. If we are ever to replace the eroded soil, then we must pay 52,200 Rials for each cubic meter. Notice that this is only the price for the soil replaced and that the replaced soil may lack the nutritional value of the eroded soil. Notice also that this price is only for soil carried form the neighborhood whereas higher transportation costs may be needed to transport soil from farther areas. The 52,200 Rials multiplied by the legal fees will yield the final price for one cubic meter of soil. The cost has been estimated for the year 2004.

$$52,200 \times 1.3 \times 1 \times 1.04 = 85395 \text{ Rials}$$

Thus, the economic benefit of one cubic meter of eroded soil controlled is assumed to be 85395 Rials

5. The income resulting from controlling floods in the region is incalculable since if it is assumed that the downstream waterways possess a capacity for *n* cubic meters of flood and further that if only one cubic meter is taken off from the peak flood flow in order to prevent a destructive flood, then we must have appropriate and accurate plans to take off one cubic meter of the flood flow.
6. We have assumed a cost of 1500 Rials to recover one m^3 of the infiltrated water.
7. Two options of 25 and 50 years have been assumed for the effective life of watershed management projects.
8. The quantity of infiltrated water has been computed according to operations type and relevant tables.
9. The water directly harvested has been computed according to the volume of earth dam reservoirs and TOURKINSTS

10. Conclusions

The main objective of this survey was to compute economic indices for watershed management projects in a uniform and coordinated computational system for the state planning bodies in their attempts to prioritize projects. Along these lines, the basic data from different projects were, first, collected and then subjected to assessment, examination, remediation and corrections in the basic data and, finally, the selection of the methodology and computation models was accomplished.

Investigation of arid and semi-arid zones and the lessons learned from this survey indicate that there are great potentials for water saving and harvesting several times the quantity secured by conventional methods once rainfall is harvested and water losses and evaporation of precipitation are prevented.

Evaluation of 30 projects executed in Iran revealed that the average execution time was 1.5 years and that they were executable in all locations across the country in a rapid manner. The benefit to cost ratio for these projects ranged between 2 and 150 times. On the average, this ratio for the projects surveyed was found to be 8 times the initial investment. With execution of rainwater harvesting schemes, flood flows in wet years can be controlled economically but only with public participation and appropriate investments. This will additionally prevent evaporation of rainwater, refine and purify muddy waters, and supply the harvested water for agricultural, industrial, and drinking demands. It is even possible to take advantage of relative sloping and gravity to reuse the water many times.

References

- Report on "Watershed Management and Aquifer Management National Scheme to Alleviate Drought Impacts, Water Shortage, and Improved Productivity of Precipitation (Warrants and Priorities)" (In Persian), Planning Bureau, Watershed Management Deputy, summer 2006.
- Report on "National Research Project on Hydrologic Processes in Watersheds" (In Persian), State Supreme Council on Research, 2005.
- Report on "Critical Zones and Plains" (In Persian), Tamab Organization, Ministry of Energy, 2005.

Use of rainwater harvesting for alleviating poverty in rural areas. ACSAD experience in the Arab region

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Abstract;

Water scarcity is considered one of the key challenges to agriculture and rural development in the Arab region. Freshwater share per capita has greatly reduced from 3300 m^3 in 1960 to around 1000 m^3 in 2005. Of the ten most water scarce in the world, 8 of the Arab countries top the list. Many countries in the region are facing severe pressures due to limited opportunities for the exploitation of new water resources and most of them are over-exploiting their available water resources (mainly groundwater) .These pressures are expected to increase in the face of expanding populations and the increased per capita water use associated with economic development. Frequent drought events occur in the region and increase pressure on available water resources. The effects of drought are generally serious for the poor, because they are the most dependent on natural resources for their basic livelihoods and they have the least means to avoid or cope with the consequences. Since the water resources are severely depleted in several areas, the optimal use of precipitation is warranted. Rain water harvesting is considered crucial for rural development.

In the light of these challenges this paper attempts to show how by implementing an adequate rainwater harvesting structures in rural areas (to ensure that the water harvested remains available after the rain or the rainy season), it is possible to overcome the shortage in water and improving the livelihoods of local communities .The challenges with this issue is to ensure that rainwater harvesting structure is managed in such away that it is sustainable and that it provide an equitable water share to all the poor.

The paper describes also the ACSAD package intervention in the study area by building a hill reservoir of 7000 m^3 for providing the local farmers with water during dry seasons and for use in supplementary irrigation and summer crops. New varieties of ACSAD wheat seeds which support the local climatic conditions (mainly freezing) and have early maturing and with high productivity rate have also been delivered to them in addition to scientific advice.The paper describes also the benefits obtained by the farmers from such intervention. In conclusion the paper gives some research results regarding the use of modeling technique and GIS for calculating runoff coefficient.

Water Harvesting Techniques in the Arab Region

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Abstract

The Arab world is facing one of the severest water scarcities in the world. The aridity, low rainfall, high evaporation, uneven distribution of water resources, complexity of the hydro-political conditions, the rapidly growing human population, the deterioration of water quality and the accelerated demand for water are factors contributing to water resources vulnerability in the Arab Region. Water availability per capita is continuously decreasing and water shortages are rapidly growing. As long the water demand continuously increases, the Arab conventional water resources, particularly groundwater resources, will be always stressed and depleted. Accordingly, there is a great need for effective and efficient use of all water resources potentialities in the Arab region. The total average annual volume of rainfall within the boundaries of the region is about 2,238 billion m^3 contributing only 200 billion m^3 of renewable surface and groundwater resources. Consequently, water harvesting can be a key element to alleviate water scarcity problems in the Arab region. Different water harvesting techniques have been widely practiced in the Arab region from a long time ago. This paper outlines some of the water harvesting techniques in the Arab region. Moreover, water harvesting projects in two major wadis in Egypt are presented and discussed.

1. Introduction

The total surface area of the Arab region is approximately 14 million km^2 extending between latitudes 4º S and 37º 22` N covering southwest Asia and North Africa. Most of the Arab countries are located in arid and semi-arid zones. It is characterized by scanty annual rainfall, very high rates of evaporation and consequently extremely insufficient renewable water resources. The total average annual volume of rainfall within the boundaries of the region is about 2,238 billion m^3 contributing only 180 billion m^3 of renewable surface and groundwater resources. Additionally, the region receives 160 billion m^3 of surface water from catchments outside the Arab region (UNESCO Cairo, 1995). The renewable water resources in the Arab region have been estimated by many researchers. Salih (2002) pointed out that the published figures range from 246 to 441 Billion m^3 with an average of 340 Billion m^3. This amount of renewable recourses can not meet the future needs of the Arab region.

The Arab conventional water resources, particularly groundwater resources, have been considerably stressed and resulted as depletion of the storage associated with deterioration of groundwater quality. The average annual recharge to groundwater is estimated at 45 Billion m^3, whereas 135 Billion m^3 is available in wadi system. This indicates the potentiality and importance of maximizing water harvesting in the Arab region. Moreover, in most of the Arab countries, wadi flow constitutes an important source which could be recharged to strained aquifer systems confront problems of depletion and degradation of eater quality. Since water shortage is becoming a major constraint for socio-economic development in the Arab region, most of the Arab countries have focused attention to the development of water resources of ephemeral wadis through different water harvesting techniques.

2. Rainfall-Runoff Characteristics

There is a severe spatial rainfall distribution over the Arab region (Figure 1). Only 2.66 million Km^2 receives 1488 billion m^3 constituting 19% of the total area of the Arab region, while 406 billion m^3 of rain fall on 15% of the total area. Two thirds of the Arab region which is arid and hyper-arid deserts (9.24 million Km^2) receives 344 billion m^3 of rainfall

According to the rainfall regime, the Arab region can be divided into three sub-regions, namely (UNESCO Cairo, 1995):

1. *The Mediterranean (northern) sub-region:* Rainfall is high over the coastal mountains of Lebanon (1500 mm/yr) and decreases southwards to about 400-500 mm/yr in Jordan. Moreover, in

Morocco, the annual rainfall reaches 1800 mm and it decreases southwards over the high plateau and Sahara Atlas to about 500 mm dropping to100-200 mm on the slopes adjacent to the Sahara.

2. *The Arabian Peninsula:* The rainfall is low with significant temporal and spatial distribution. The average annual rainfall ranges from 70-130 mm/yr except in some locations in Saudi Arabia, Yemen and Oman where more rainfall is received.

3. *Southern sub-region region:* Most of the area of Mauritania and Somalia has an annual rainfall of less than 300 mm/yr. In Sudan, there is a wide rainfall variation from 1800 mm/yr in south Sudan to 25 mm/yr at its boarder with Egypt.

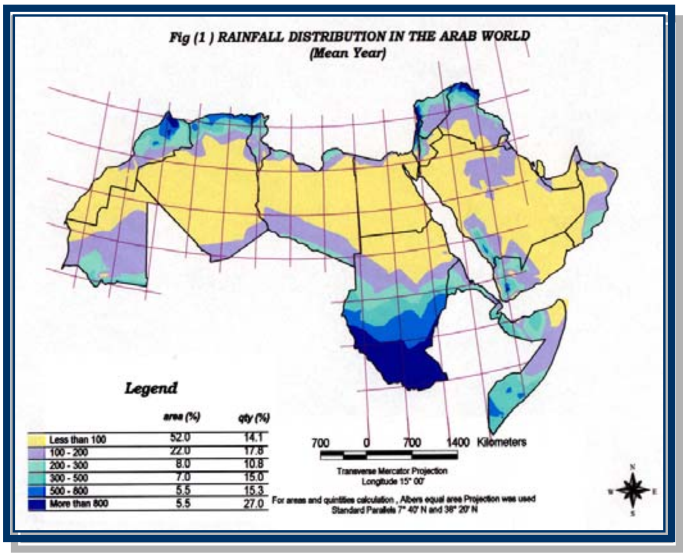

Figure (1) Rainfall Distribution in the Arab region (ACSAD, 2000)

3. The Water Harvesting Concept

Water harvesting is the capture, diversion, and storage of rainwater for many uses (Abdo and Eldaw, 2004). Water harvesting deals with all methods which manage rainfall and runoff through effective storage in the soil or underground for later beneficial use.

A water harvesting system is a facility for the collection and storage of runoff water. Systems which harvest water from roofs or ground surfaces are classified as “rainwater harvesting”, whereas systems which collect water from water courses are classified as “floodwater harvesting”. Survey of traditional water systems has revealed that some 25 systems are used in the Arab region. Promising traditional water systems have been grouped into four categories (UNESCO Cairo, 1995):

a. Water harvesting and storage systems;
b. Water harvesting and spreading systems;
c. Groundwater systems; and
d. Water lifting systems.

Table (1) Distribution of traditional water system in the Arab States, after UNESCO Cairo (1995)

Category	**Name of system**	**Jordan**	**Un-Arab Emirates**	**Bahrein**	**Tunisi**	**Algeria**	**Saudi Arabia**	**Sudan**	**Syria**	**Iraq**	**Oman**	**Qatar**	**Kuwait**	**Lebanon**	**Libya**	**Egypt**	**Morocco**	**Mauretania**	**Yemen**
Water harvesting and storage systems	Cisterns	x			x				x	x				x	x	x	x		x
	Small dams	x	x		x	x	x	x	x	x				x	x	x	x	x	x
	Hafirs	x					x	x	x	x		x	x	x				x	x
	Tree trunks							x											
	Koroum / Ghadirs	x					x	x		x				x		x	x		
Water harvesting and spreading systems	Terraces / Masateh	x			x	x	x		x	x				x	x		x		x
	Irrigation diversion dams	x			x	x		x	x	x				x		x	x		x
	Water spreading dykes	x				x	x	x	x	x				x		x	x	x	
	Miskat				x										x				
	Artificial recharge	x	x					x				x				x	x		x
	Check dams				x										x				

Groundwater systems	Foggaras		x		x	x	x		x	x	x			x	x	x	x		
	Surface wells	x	x		x	x	x	x	x	x	x	x		x	x	x	x	x	x
	Springs	x			x	x	x		x	x	x	x		x	x	x	x	x	x
	Ghoutas					x	x								x	x			
Water lifting systems	Shadouf					x		x		x						x	x	x	
	Saquia / Naoura				x			x	x	x						x	x		
	Tambour															x			
	Bucket and pulleys	x			x	x	x	x	x	x				x	x	x	x	x	x
	Wind mill				x			x	x					x	x	x	x		
	Hydraulic mill																x	x	

security in many communities like in Yemen, where, more 1.5 million hectares have been regularly cultivated (Abdulrazzak, 2003).

Table (1) shows the distribution of the different traditional water systems in the Arab countries. It worth mentioning that water harvesting in the Arab region dates back to 9000 years ago. The earliest systems are located in Jordan, Iraq and the Arabian Peninsula (Abdo and Eldaw, 2004).

In arid and semi arid areas, the main purpose of water harvesting is for growing crops or for rehabilitation and development of rangelands. Harvesting one millimeter of rainfall is equivalent to one liter of water per square meter. Accordingly, the catchment area is a major criterion for classifying water harvesting systems as follows:

1. Micro-catchment water harvesting systems where the catchment area and cultivated area are adjacent. It belongs to rainwater harvesting systems. Negarim microcatchments (Figure 2) and contour bunds (Figure 3) are examples of this water harvesting technique.
2. Macro-catchment water harvesting systems where the catchment area is located upstream the cultivated area, in most cases called external catchment system where overland flow is harvested.
3. Spate irrigation system which depends on harvesting flood water from wadi channels. Their catchment area is larger than the other two systems.

Figure (2) Negarim microcatchment

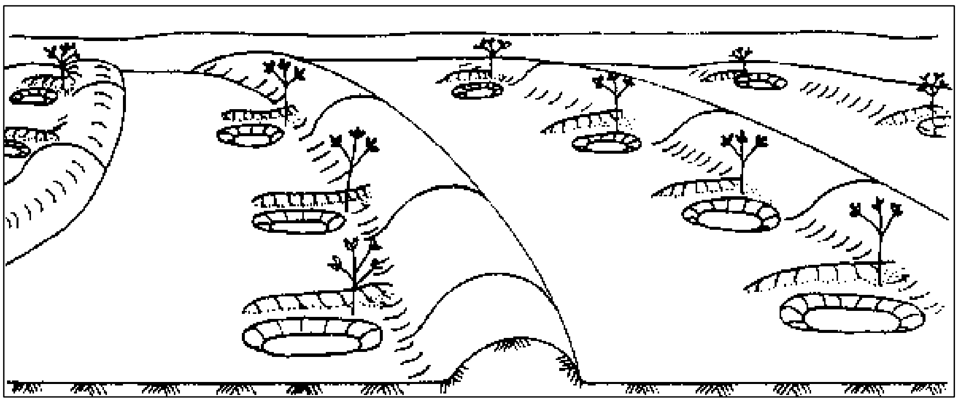

Figure (3) Contour bunds for trees as a simplified form of microcatchments (after FAO, 1991)

4. Terracing

Terracing is widely used in Yemen as one of the effective conservation techniques (Figure 4). Moreover, it is successfully used for rainfall utilization and soil conservation in the mountainous areas of south western Saudi Arabia and Oman. Different forms of terracing are available depending on its purpose such as soil conservation and water use. In the Arab region, there are a number of practiced terracing systems such as weir terraces across narrow wadis, barrage terraces, linear dry field terraces, and stair terraces (Abdo and Eldaw, 2004). Rained agriculture is practiced on terraces achieving food

Figure (4) Terraces on mountain slopes in the Yemen Highlands (after Noman, 2003)

Lack of maintenance, migration of labor and emphasis on large scale agricultural development are the main problems of terracing in the Arab region (Abdo and Eldaw, 2004).

5. Spate Irrigation

This kind of water harvesting may also called flood irrigation. It mainly counts on water spreading where the flood water is diverted from the wadi course to an immediately adjacent cultivated area. Spate irrigation is practiced in Sudan, Yemen, Oman, United Arab Emirates, Tunisia, Algeria and Saudi Arabia. Ahmed (2005) stated that agricultural land may be graded and divided into basin for storing enough water to allow enough water to be stored for the season. Therefore, soils should be deep with sufficient water holding capacity. Table (2) provides some figures about the spate irrigation areas in some Arab countries in relation to the total irrigated areas in these countries, (FAO, 1999)

In large wadis with high discharges, a temporary earth dams created in order to retard the flow and receive the first wave of flood. The traditional methods practiced in Yemen ad several Arab countries consists of constructing earthen bunds (Ogmas) ahead of the rainy season across the wadi channel to direct the floodwatrer. This is a cheap system to build however, it needs regular maintenance and repairs from flood damages.

Table (2) Spate Irrigated areas versus total irrigated areas in some Arab countries (FAO, 1999)

Country	**Year of Irrigation data**	**Spate irrigation area in ha**	**Total irrigation area in ha**	**% of spate irrigation coverage**
Yemen	1987/1997	98,320	481,520	40
Algeria	1992	110,000	555,500	20
Morocco	1989	165,000	1,258,200	13
Tunisia	1991	30,000	385,000	8
Sudan	1995	46,200	1,946,200	2.5

In eastern Sudan the spate irrigation system in the ElGash seasonal river delta involves several uncertainties due to unpredictable in timing, volume and sequence of flood water. Such situation represents the main cause of risks in crop production and uncertainties under spate irrigation. The spate irrigation system in El Gash wadi is consisted of six main canals. These canals are crossing the wadi deltas from East to West with a bed slope ranges from 1:1000 to 1: 2000 (Ahmed, 2005). The control structures along the canals are operated by stop-logs. Heavy sediment load of the river creates the closure of the canals. Basins of 1000-1500 ha is watered for more than 40 days continuously leading to heavy water losses through evaporation (400 mm) and deep percolation which reaches 6m deep. The wetted area in the ElGash Scheme is about 40,000 Feddans. About 36,000 farmers is working this scheme. The irrigated lands are rotated from year to another. As pointed out by Ahmed (2005), the rotational use of land by the lottery system is one of the main problems complicating the spate irrigation water management.

In many areas of the Arabian Peninsula, direct use of flood water for irrigation or groundwater recharge is small compared to the amount of available surface runoff. Water spreading involves the percolation of excess water into shallow groundwater alluvial aquifer. This method is used in Saudi Arabia, Yemen, Oman and United Arab Emirates. There are many examples of either indirect artificial recharge projects in the Arab region. In Qatar water is collected in shallow depressions and injected into the underlying aquifers through wells.

Beyrouth artificial recharge project is one of the earliest applications of artificial recharge in the region. Surface water has been diverted from streams flowing in karstic terrain to the limestone aquifer in coastal areas and was recharged through a number of wells. It was pumped during dry seasons when the base flow of streams become insufficient to meet peak demand in Beyrouth. This pilot project demonstrates that artificial recharge could be used for addressing water supply problems arising from high degrees of karstification in the main channels of perennial or intermittent streams flowing in limestone terrains (UNESCO Cairo, 1995).

The majority of dams built in Oman and UAE are for recharge of depleted aquifer systems. In addition to surface dam few “sub-surface dams” have been built to regulate groundwater flow. Dams built on Wadi Aridah and Wadi Turba ner Taif in Saudi Arabia are examples for this kind of wadi development (Al-Hajeieiry and Shaikh, 1982). It was noted that after the construction of these dams an amount of 6.5 million m^3 were made available instead of losing it due to seepage to highly permeable wadi-fill deposits which was the case before the dams construction.

In Oman, usually stored surface water upstream dams last for almost 15 days after which the stored water is diverted to spreading grounds beside the wadis. These areas usually exist downstream and water reaches them through channels dug for this purpose.

6. Meskat

The Miskat System is one of the ancient methods employed in harvesting rainwater. They are used in the Arab Maghreb specially in Tunisia, Morocco and the north west of Libya in Nafousa mountain. At present, the state of these Miskats have been deteriorated because of the intensive agricultural development that took place since the middle of the century (UNESCO Cairo, 1995). The Miskat secures water deficit resulting from the difference between water consumptive use of the crop in the basin (Manka') and the available annual rainfall. The deficit is covered by harvesting water during the period of rainfall occurring over an area called Miskat. This water is later diverted to the basins where it is stored in the soil. The Miskat (Figure 5) is simply a piece of flat land with a mild slope (3 to 6%) with few or no drainage channels. The land is prepared for rain water harvesting and then water is directed to another piece of land of half its area and located directly below; which is called the collector where crops are planted.

In Tunisia, the "Meskat" and the "Jessour" systems are widely practiced. The "Jessour" system (Figure 6) is a terraced wadi system with earth dikes reinforced by dry stone walls. The sediments accumulating behind the dikes are used for cropping. Most "Jessour" have a lateral or central spillway (Prinz, 1996). Up to 1984, "Meskats" covered 300,000 ha where 100,000 olive trees were planted; "Jessours" covered 400,000 ha (Tobbi, 1994). The government of Tunisia started in 1990 adopted a strategy comprising the construction of 21 dams, 203 small earth dams, 1,000 ponds, 2,000 with the aim of recharging groundwater aquifers and 2,000 works for irrigation through water spreading (Achouri, 1994). Prinz (1996) indicated that modern spate irrigation techniques are harvesting about 20 Mm^3 of water annually to serve an area of 4,250 ha.

In Libya, Al-Ghariani (1994) indicated that on the slopes of the western and eastern mountain ranges, runoff-based farming agriculture are practiced. Historical studies have noted that such techniques were used during Roman times. In different parts of Libya, experimental sites of contour-ridge terracing covering more than 53,000 ha have recently been established (Al-Ghariani, 1994).

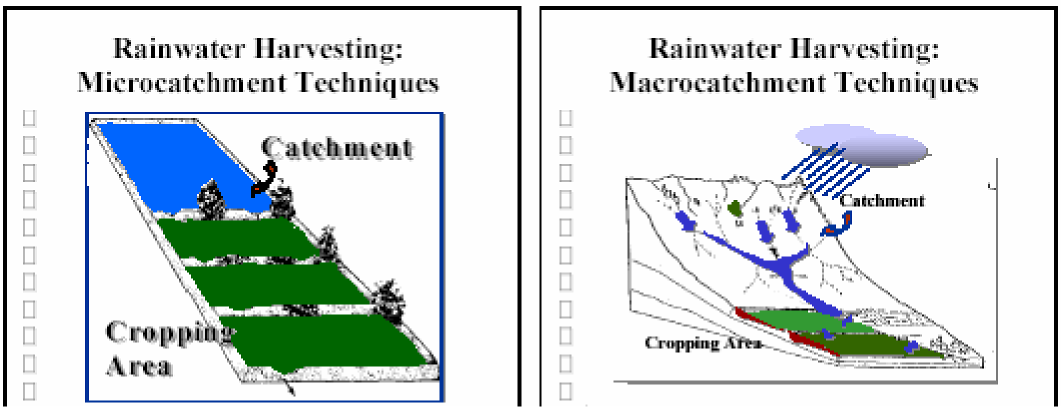

Figure (5) Examples of rainwater harvesting techniques with general features. Microcatchment: Meskat system from Tunisia (Prinz 2002)

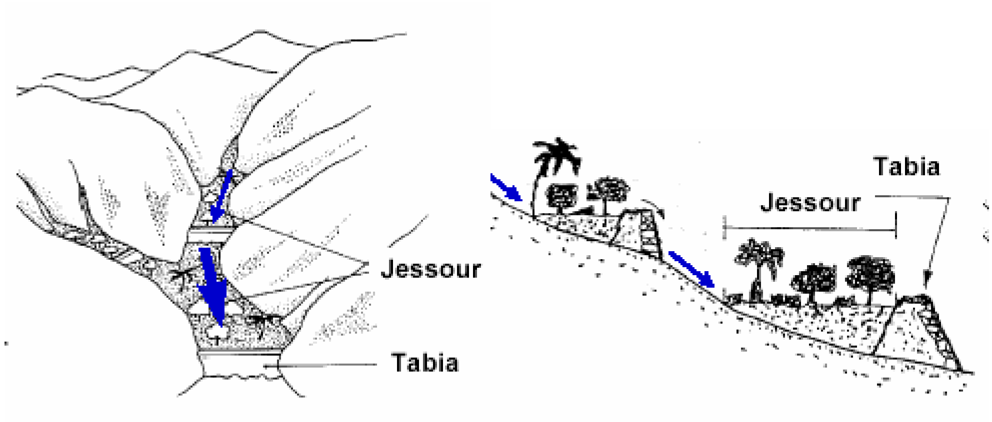

Figure (6) A row of "Jessour" in the South of Tunisia. (Prinz 1996).

7. Dams and Reservoirs

Dams of various sizes were constructed in most Arab countries for the purposes of irrigation, flood control and groundwater. Dams assist in reducing flood damage downstream by reduce the magnitude of peak discharge. Moreover, sediment which carried by floods is trapped upstream dams creating good soil for agriculture. Most of the dams built in Saudi Arabia, the United Arab Emirates and Oman were built for the purposes of groundwater recharge flood control (Abdulrazzak, 2003). Few large dams in Saudi Arabia, Egypt, Tunisia, Sudan and Jordan have multi-purposes (Abdo and Eldaw, 2004). These dams have been built either at the head waters of catchments in the mountainous regions or in the downstream portions of catchments as in Saudi Arabia, Sudan, Egypt, Tunisia, Jordan, Yemen, the United Arab Emirates, and Oman. Abdo and Eldaw, (2004) stated that due to flat topography and limited runoff in the remaining countries of Bahrain, Kuwait and Qatar, and parts of Sudan small diversion structures are used instead of dams to create detention basins.

8. Water harvesting projects in two major wadis in Egypt: Case Studies

8.1 Wadi Watier

Wadi Watier (about 3600 km^2) in southeastern Sinai, Egypt receives large amount of rainfall. Wadi Watir is distinguished with its strong flash floods, appropriate fruitful soils for cultivating, inhabitance with Bedouins, natural springs, constructed wells, and tourism Canyon area. Moreover, at the delta of the Wadi, there are Nuweibaa City, many tourism villages, and roads network. The floods of Wadi Watier usually cause huge destruction in the area and endanger the life of people (see Figure 7).

The catchment area is covered by basement rocks, mainly granites which are highly fractured and intruded by basic dikes trending in NE-SW direction. The basement rocks are non-conformably over lain by Cretaceous rocks, mainly sandstones followed by shales and limestones (Fahmi et al., 2002). Figure (8) shows the general classifications of the land cover in wadi Watier. Alluvial deposits derived from local rocks fill the drainage streams of the Wadi.

Figure (7) Destruction effects of Wadi Watier flash floods

For the purpose of water resources development of the area and to minimize the harmful destruction effects of Wadi Wateir flash foods, seventeen detention dams and five storage dams are proposed. These dams store direct water for seasonal agriculture sufficient to irrigate about 4500 feddans/year. Moreover, reuse of recharging water for groundwater aquifers, as indirect contribution, can cover the requirements of about 3000 feddans/year. Another positive impact is the creation of a good agriculture-land upstream the proposed structures amount to about 500 feddans. Fahmi et. al. (2002) indicated that the costs of structures can be compensated within few years after executions of the proposed control works.

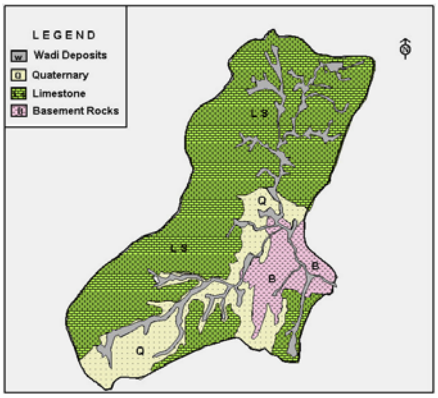

Figure (8) General Geological Map of Wadi Watir

Dams locations were selected upon field investigations according to the most practical and suitable sites. Figure (9) gives example of Wadi Wadi Watier dams. This includes construction process and transportation of the equipments and materials. The hydrological aspects of reservoir planning deal with:

1. Water availability in the area on which the dam is proposed to be constructed;
2. Determination of storage capacity to serve the target pattern of demand; and
3. Operation of reservoir with the given target pattern of demand.

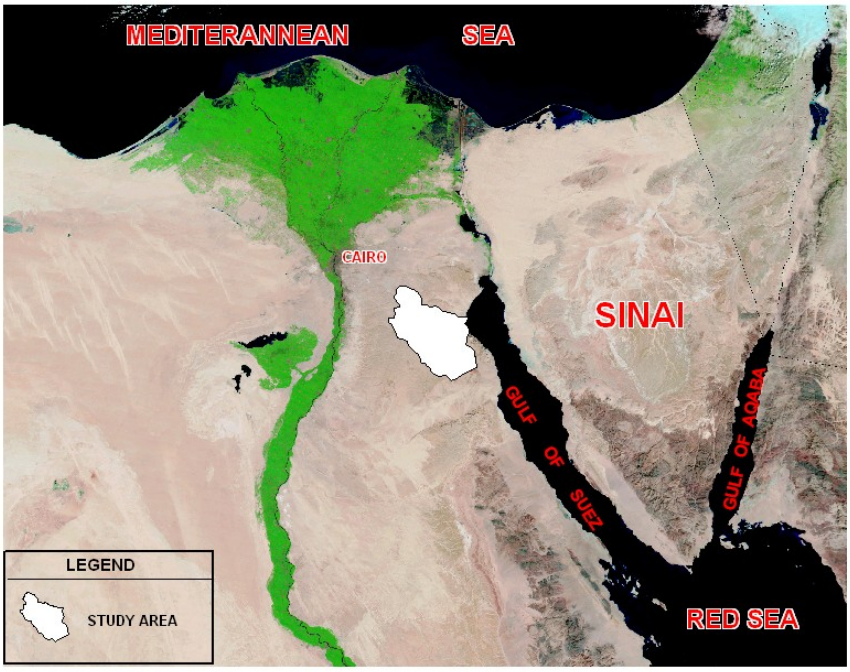

Figure (9) Wadi Watier dams example

8.2 Wadi Ghuweiba

On the other side in the Eastern Desert of Egypt, Wadi Ghuweiba extends between Lat. 29º 10' and 29º 45' E and Long. 31º 40' and 32º 30' N. It covers an area of about 2500 km2 and main stream length of about 130 km. The Wadi is generally rugged with strongly slopes range between 10 and 28 m/km and elevations between 1300 m to about 100 m (See Figure 10).

The area mainly consists of Eocene limestone outcrops all over the area and overlained by wadi deposits and underlained by different types of rocks. The thick limestone formations attain a thickness of more than 400 m underlained by Esna shale and upper Cretaceous limestone and a thick section of sandstone belong to lower Cretaceous and Paleozoic ages (Fahmi et. al., 2004). The delta of this wadi is characterized by gradually sloping irregular surface dissected by fan drainage lines and covered by alluvial deposits which is considered as an important source of Quaternary groundwater that can be withdrwal by shallow dug wells taking into consideration the sea water intrusion from Suez Gulf due to over pumping. Permeability coefficients along wadi Ghuweiba main stream, at the outlets of each subbasin, have been measured as listed in Table (3).

 

Figure (10) Location Map of Wadi Ghuweiba

Table (3) Permeability coefficients at subbasins' outlets (after Fahmi et. al., 2004)

Subbasin's Name	Shona and Khafory	Esaimer	AA	Abiad	Noot	Ghuweiba
Permeability (cm/sec)	1.95 x 10-1	2.15 x 10-1	1.8	4.5 x 10-1	4.5 x 10-2	1.6 x 10-1

Field geoelectrical survey was conducted in Wadi Ghuweiba comprising 16 vertical Electrical Sounding (VES) using Stumberger electrode configurations. The location of these VES's is shown in Figure (11).

Field measurements aimed to explore a depth of about 700 meters. The main purpose of interpretation of geoelectrical resistivity sounding is to determine the number of geoelectrical layers in terms of thickness (or depth) and relative true resistivity. Interpretation of vertical electrical soundings has been correlated with some available boreholes, thus, a reliable control can be achieved for portraying the subsurface picture in the study area. The results of such interpretation in the form of layer thickness and true resistivities are illustrated on the geoelectrical cross-sections (Figure 12).

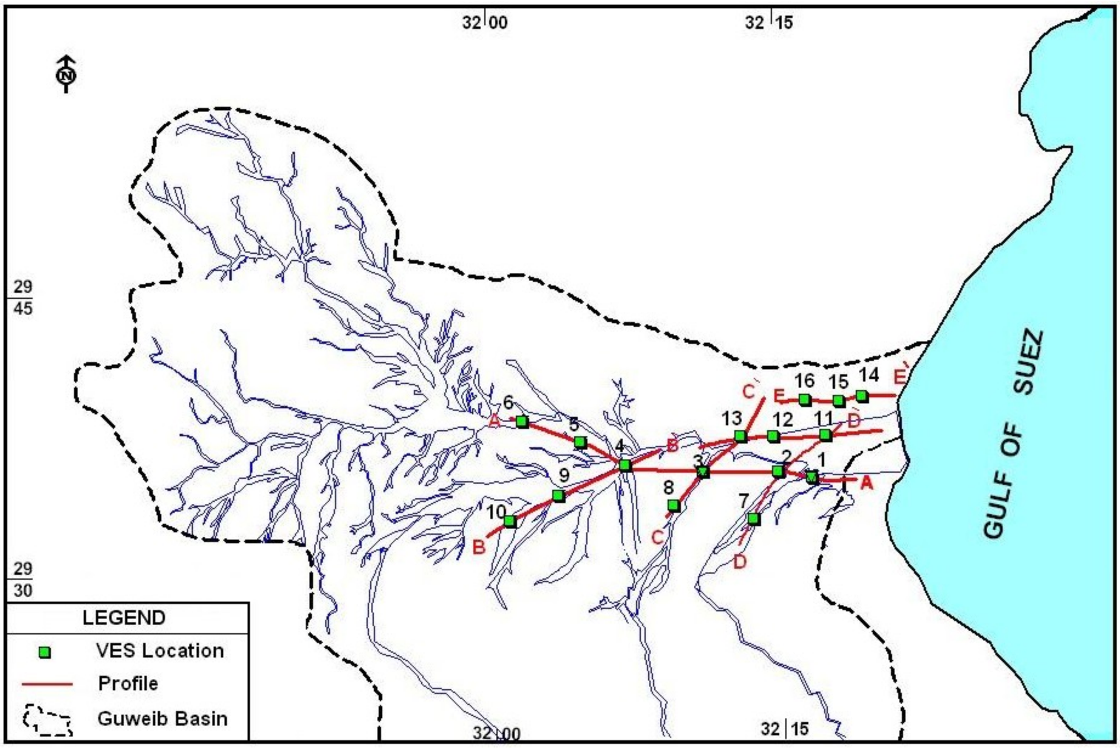

Figure (11) VES Location and Profile Direction in Wadi Ghuweiba

From this investigation, it can be pointed out that there are two main aquifers in Wadi Ghuweiba area; the upper Quaternary aquifer which can be harvested by drilling wells to a depth of about +150 m, and the second is the Tertiary aquifer which can be harvested by drilling wells of about +450 m (Fahmi et. al., 2004).

To increase the rate of recharge to the Quaternary aquifer, an artificial recharge system was suggested. Six locations were employed to induce infiltration into the Quaternary aquifer using of instream structures. These structures were series of rechargeable dams which are changing the hydraulic regime of wadi Ghuweiba stream, decreasing flow velocities and encouraging the growth of riparian vegetation.

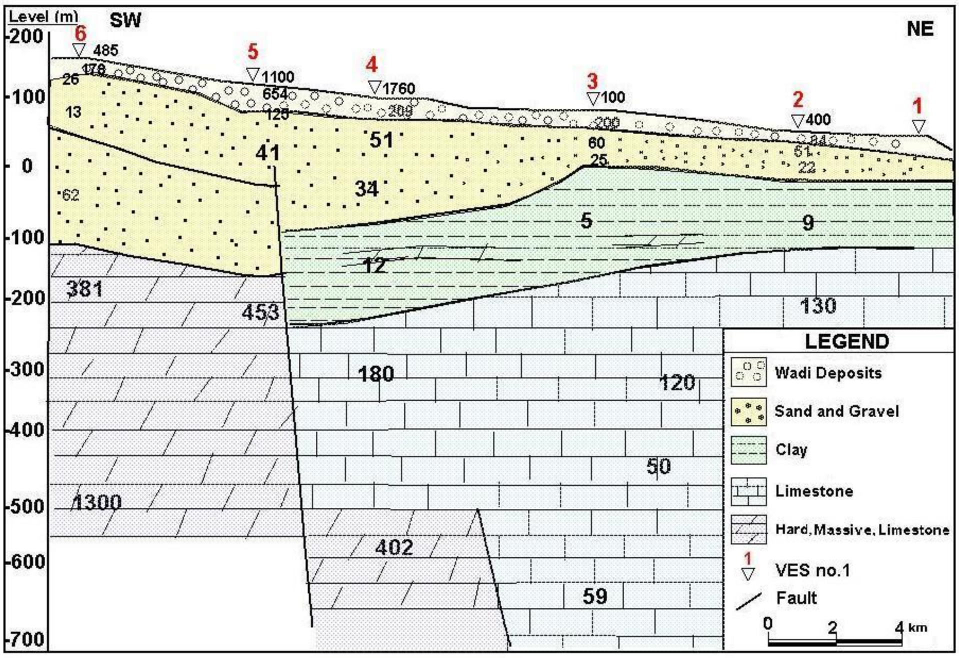

Figure (12) Geoelectrical Cross-Section along Wadi Ghuweiba Main Stream

Moreover, they aid in the replenishment of subsurface and groundwater. Dams' heights ranged between 3 and 7 meters with capacities ranged between 60x103 to 6500x103 cubic meters. Figure (13) shows the location of dams and their expected storage area in Wadi Ghuweiba. The dams are designed to fill with course sediment over a period of several years following construction. The sediment behind the dams serves as an artificial aquifer for the storage of flood waters and their eventual release as streamflow.

Table (4) shows the recharged water to the different groundwater aquifer. Development and settlement criterion are preferable to be based on the average seasonal rainfall and the considerable floods happened in a specific return periods.

9. Water Harvesting Constraints in the Arab Region

The following lists some of the constraints facing water harvesting in the Arab region:

- Rainfall and runoff data availability
- Un-gauged Catchment conditions
- Suitable hydrological techniques for arid conditions
- Up-scaling problems from experimental catchments (if exist) to water harvesting scale
- Socio-Economic aspects
- Maintenance
- Financial support for establishing monitoring systems
- High cost of water harvesting constructions in the Arab region in relation to its immediate use.

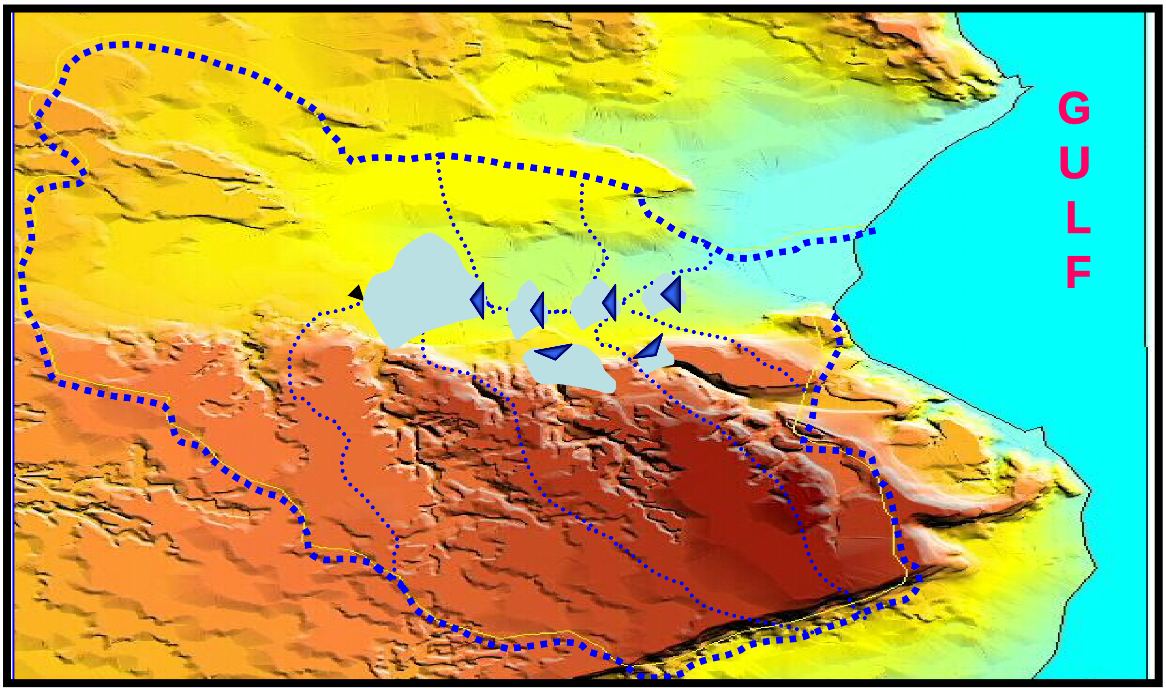

Figure (13) Location of dams and their storage area in Wadi Ghuweiba

Table (4) Recharged water to different aquifers (1000 m^3)

Subbasin's Name	**Average**	**Return periods (years)**				
		5-yr	10-yr	25-yr	50-yr	100-yr
Shona	1260	840	3360	5460	10440	13320
Khafory	2501	2066	3515	7760	11360	13930
Esaimer	88	88	184	264	516	814
Abiad	43	36	70	180	228	598
AA	638	510	829	3168	3550	13345
Noot	46	23	57	132	234	435

10. Recommendations

1. Strengthening the existing hydrological monitoring systems in the Arab region
2. Establishing more new experimental basins in the Arab region for more understanding of the hydrological characteristic of the region.
3. Establishing regional database and strengthening the existing ones in the Arab region.
4. Encouraging more joint research activities in arid zone hydrology.
5. Enhancing capacity building and fostering networking in the field of water harvesting in the Arab region.

6. Raising public awareness for increasing the water use efficiency with special focus on the ethical dimension.
7. Encouraging the involvement of the stakeholders, NGOs and communities in th maintenance of he water harvesting construction.
8. Enhancing the coordination among the scientific institutes in the Arab region for more experience exchange in the field of water harvesting techniques.

References

Abdo, G. M. and Eldaw, A. K., 2004, "Water Harvesting Experience in the Arab world, Regional Workshop on Management of Aquifer Recharge and Water Harvesting in Arid and Semi-Arid Regions of Asia, Yazd, Iran, pp. 79-99.

Abdulrazzak, M. 2003, "Water Harvesting Practices in selected countries of the Arabian Penisula, Proc. Conference on Water Harvesting and the Future Development in Sud, 19-20 August, Khartoum, Sudan.

Achouri, M. (1994). "Small-scale water harvesting: A case study of water spreading on the perimeter of Boudaoues (Kairouna, Tunisia)". Proceedings of the FAO Experts Consultation, Cairo, Egypt.

Ahmed. A. 2005, "Wadis Systems Management with Emphasis on Sudan Experence", Proceeding of The Third International Conference on Wai Hydrology, Sana'a, Yemen.

Al-Ghariani, S. (1994). "Contour ridge retracing water harvesting systems in north-west Libya". FAO, Water Harvesting For Improved Agricultural Production. ExpertConsultation, Cairo, Egypt, 35-56.

Fahmi, A.H., M. Sherief, M. S. Farid, (2002), "Integrated Solution to Flash Floods Problems In Wadi Watier, South Sinai, A.R.E", Proceeding of the Int. Conf. on Water Resources Management in Arid Regions, Kuwait.

Hassan Fahmi, A. H., G. Kotb, Osama A., N. A. El-Bahnasawy, and M. Mottaleb, (2004), "Evaluation Of Water Resources In Eastern Desert, Se Study Wadi Ghuweiba, Gulf Of Suez, Egypt", Proceeding on the Second Regional Conference On Arab Water 2004 Action Plans for Integrated Development.

Noman, A. A. (2003), "Water Harvesting and Spate Irrigation in Wadis" Yemen Case", Proceeding of Second International Conference on Wadi Hydrology, Amman, Jordan

Prinz, D. (1994). "Water harvesting and sustainable agriculture in arid and semi-arid regions". Proceedings, CIHEAM Conference "Land and Water Resources Management in the Mediterranean Region", Valencano (Bari),. (III) 745-762.

Salih, A., 2002, UNESCO Contribution to Fresh Water Scarcity in the Arab Region, UNESCO, IHP Division, Paris

Tobbi, B. (1994). "Water harvesting: historic, existing and potentials in Tunisia". In: FAO, Water Harvesting For Improved Agricultural Production. Expert Consultation, Cairo, Egypt. 189-201.

UNESCO Cairo, 1995 "Rainfall Water Management in the Arab region", State of the Art Report, edited by J. Khouri, A. Amer, and A. Salih.

Indigenous knowledge for using and managing water harvesting techniques in Yemen

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Abstract

Yemen is a country suffering water shortage. Therefore rainwater harvesting is a common practice since the antique. Ruins of dams and reservoirs as well as the unique, spectacular mountain terraces, confirm the long history of water harvesting. The great historical Marib dam and its collapse are mentioned in the Holy Koran. Recent archaeological excavations discovered ruins of irrigation structures around Marib city dating from the middle of the third millennium BC (some 4000 years ago). Farmers in this same area are still irrigating with floodwater, making the region perhaps one of the few places on earth where runoff agriculture has been continuously used since the earliest settlement.

Villagers in the mountainous areas are well acquainted with ware harvesting systems for hundreds of years. They use the collected water for drinking, animal watering and supplementary irrigation particularly in the drier seasons. They mainly building cisterns to collect run off from clear and well selected catchment areas well away from the villages to prevent pollution. Old local manufactured material such as *Khadad* is used to cement the cisterns which proved to be of high quality and can withstand all environmental changes such as weather, rain, temperature, etc and can last longer periods. However, further research is needed on such material.

This study aims to describe the state of the art of water harvesting techniques in Yemen. Also, it emphasizes the integrated development of water resources in wadi systems, through the application and development of technologies. It based on real experimental applications and development initiatives. This study concludes by evaluating the approaches of applied methodologies for sustainable development of surface water recourses of wadis, the role of Rain Water Harvesting and the appropriate techniques and their relative viability. Viable techniques has identified and described in some details in order to facilitate and promote the transfer of experience and exchange of know-how in the Arab region.

Key words: water harvesting, spate irrigation, wadis, traditional techniques

INTRODUCTION

Yemen, historically, had one of the oldest civilizations in the Middle East based on agricultural development, in which the people of Yemen managed to establish the spectacular mountain terraces system on the steep slopes of the rugged mountainous areas, some thousands of years ago, in order to conserve soil and to optimize rainfall water use. Yemen depends on rainfall to cultivate and produce crops, so that Yemeni people cultivate their land under rainfall conditions at large scale, and they efficiently use and control flood water and spring water. Water rights of flood water and springs were well established and efficiently used to cultivate farmland according to its location from the source of water and to agreements between land owners. It (water right) became well-known among the people, due to continuous practices and/or according to written documents which were transferred from generation to generation till today.

For centuries, Yemen was self-sufficient in food production, both crops and animals production, and the surplus was exported to neighboring countries. Recently, changes have happened to the life style and consumption pattern of the increasing population, which in turn caused increasing demand on food, water and other daily requirements. These changes encouraged the people to turn to internal and external migration, which caused abandonment of terraces and their maintenance, as well as the absence of traditional cooperation among farmers due to migration of men and shortage of labor forces and increasing labor wages (MAI, 2000).

SOCIO-ECONOMIC FEATURES

Population: The total population is around 20.0 million (MPD, 2004), of which 74.4 % is rural. The average population density is about 31 inhabitants/km^2, but in the western part of the country the density can reach up to 300 inhabitants/km2 (Ibb province) while in the three eastern provinces of the country the density is less than 5 inhabitants/km^2. This is closely related to the physical environment. By far the largest part of the population lives in the Yemen Mountain area in the western part of the country, where rainfall is still significant, although not high in many locations. The hostile environment of the desert and eastern upland areas is reflected by low population density. The average demographic growth rate is estimated at 3.5%, which is very high.

Agriculture and economy: Agriculture contributes 21% to the Gross Domestic Product (GDP) in Yemen, employs 60% of the population, and provides livelihood for rural residents who constitute about 76%of the total population. Agriculture is characterized by low and uncertain crop yields due to drought, insufficient and erratic rainfall, declining soil productivity due to soil erosion and poor crop management practices, and crop losses due to damage by insects and diseases, and malnutrition resulting from inadequate supply of feed (Figure 1). Oil has been a main activity in the Yemeni economic. In 2000, Yemeni's oil production reached 143 million barrels at a total value of 412 billion Yemeni Riyals (around 68% of total state revenues).

Cultivated land has expanded from 1.21 thousand hectares in 1990 to 1.28 thousand hectares in 2005, an increase of14% of land for cereals crops, vegetables, fruit, cash crops and animal food.

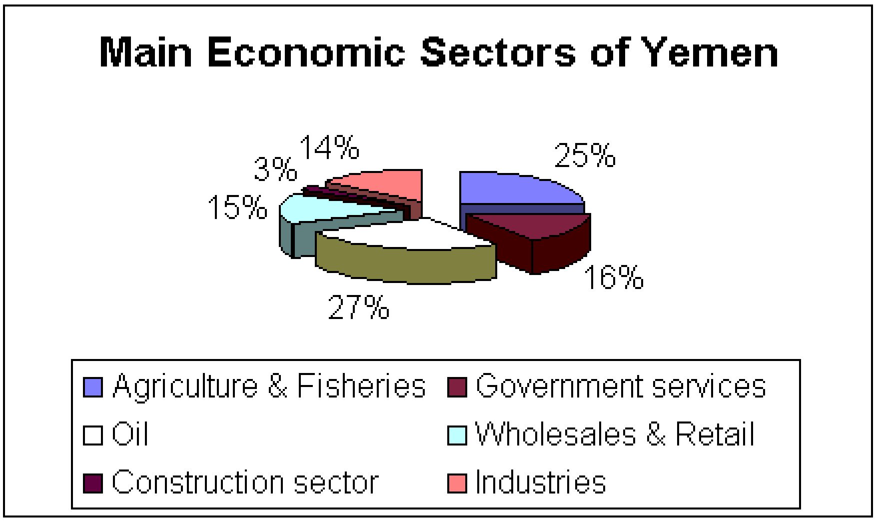

Fig.1 **Main Economic Sectors in Yemen (MAI,200)**

Land resources: Yemen is among the oldest countries in the world where land and water resources practices have been developed. Terraces erection, rainwater harvesting and dam irrigation techniques were developed since many countries ware trackless waste.

The cultivable land is estimated at about 1.67 million ha, which is 3% of the total area. In 1998, the total cultivated area was 1.28 million ha, or 68% of the cultivable area, of which 0.87 million ha consisted of annual crops and 0.41 million ha consisted of permanent crops. About 32 million ha is estimated as desert and rock outcrops, while range land are estimated to occupy 16 million ha including those areas which are covered by shrubs, perennial vegetation and grass. Only 1.5 million ha of the total area is considered as a forest and woodlands. (MAI, 2000).

Agroecological systems: Yemen is characterized by varieties of environmental zones. Since early 80s there were many attempts to classify the agroecological zones, occasionally by using the physiographic features and time to time by using landforms and climatological characteristics.

Recent demarcation of Agroecological zones in Yemen is not comprehensive, but the country could be divided into three major zones (Figure 5) derived from the five physical divisions these are:

The Coastal Region: This region includes the low coastal plains facing the Red Sea, the Gulf Aden and the Arabian Sea. Its is makes a coastal strip extending to the Omani border in the east towards the southwest to Bab al Mandab, and north wards to the Saudi border. It starches over an area 2000km long and 20-60km wide, with an altitude ranges 0-500m a. m. l. Many seasonally flowing wadis dissect the region. An arid sub-tropical climate dominates the region with average annual rainfall in the range of 50-300 mm. The climate becomes semi-arid subtropical in areas adjacent to the foothills of the western escarpment.

The Mountainous Region: This region includes the most complicated landscapes of the country. It is very irregular and dissected topography, with elevation varies from 500m at the foothills of its western and southern escarpments up to 3700m in the western peaks, then down to 1200m at its north-eastern escarpment. Due to this extreme physiographic diversity, differences in slope and location relative to the Red Sea, Gulf of Aden and Al Rub al-Khali, rainfall varies considerably within the region, with annual averages ranging from less than 300 mm to more than 1000mm. This region is divided into three main catchments, the western slopping towards the Red Sea, the southern towards the Gulf of Aden and the north-eastern towards the empty quarter (Al Rub al-Khali). The climate is characteristic of the semi-arid tropics, with limited areas of dry temperate intermountain plains at altitudes above 2000m.

Eastern plateau: This region is bordered by the mountains zone to the west, the southern coastal plains to the south and the Empty Quarter to the north. It covers vast expanses of sand desert and dissected plateau with elevation ranging from 500m on its northern and southern sides, to about 2400m on its western side. The average rainfall in this region is generally below 200mm, an arid sub-tropical climate dominates its major agricultural lands.

To show more detail with respect to aridity, a classification proposed by UNESCO (1979) can be used. It is based on the ratio between average annual precipitations (P) and annual reference evaporation (E), and in principle marks five different classes:

- hyper-arid	$P/E < 0.03$
- arid	$0.03 < P/E < 0.25$
- semi-arid	$0.25 < P/E < 0.5$
- subhumid	$0.5 < P/E < 0.75$
- semi humid	$P/E > 0.75$

Figure 2 shows the results of this classification. In terms of aridity, the climate in Yemen is shown to vary from hyper-arid (deserts, most of the plateaux, parts of the coastal plains) to subhumid (scattered wetter zones on the Western and Southern Slopes), with perhaps even humid sites on a very small scale in Ibb.

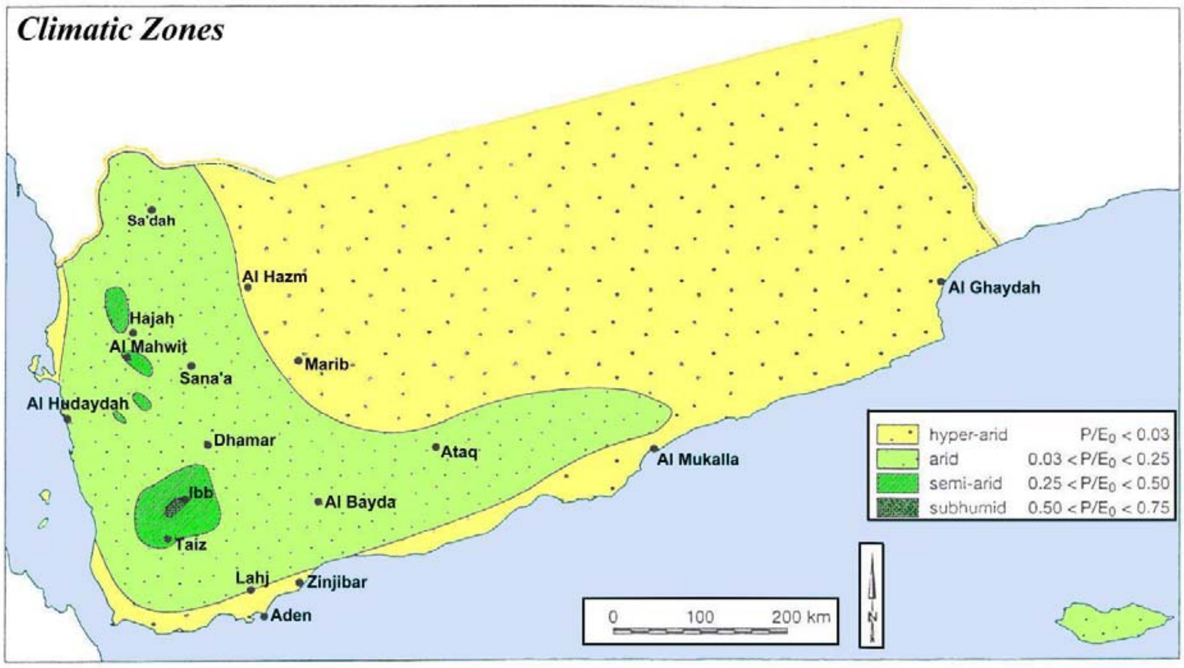

Fig. 2 Climatic zones in Yemen (Van der Gun,1995)

Land use: There is inventory of national land cover or land use, except for western northern governorate and of limited scattered areas. There is no clear boundary between land use and land cover in Yemen. Agricultural land consisting of arable land and land under permanent crops forms about 3% (of which about 450,000ha of mountain terraces is rainfed, 650,000 ha of relatively flatland in the inter-mountain region). Irrigated lands occupy some 489, 000 ha distributed as 98,000 ha spate irrigation, 28,000 ha spring irrigation and 363,000 ha well irrigation.

CLIMATE AND WATER RESOURCES

Climate: Yemen has a predominantly semi-arid to arid climate, with rainy seasons during spring and summer, and high temperatures prevail throughout the year in low-altitude zones.

The many different landscapes of Yemen can be grouped into five main geographical/ climatological regions (see figure 3):

- **The Coastal Plains:** The Plains are located in the west and south-west and are flat to slightly sloping with maximum elevations of only a few hundred meters above sea level. They have a hot climate with generally low to very low rainfall (< 50 mm/year). Nevertheless, the Plains contain important agricultural zones, due to the numerous wadis that drain the adjoining mountainous and hilly hinterland.
- **The Yemen Mountain Massif:** This massif constitutes a high zone of very irregular and dissected topography, with elevations ranging from a few hundred metres to 3 760 m above sea level. Accordingly, the climate varies from hot at lower elevations to cool at the highest altitudes. The western and southern slopes are the steepest and enjoy moderate to rather high rainfall, on average 300-500 mm/year, but in some places even more than 1000 mm/year. The eastern slopes show a comparatively smoother topography and average rainfall decreases rapidly from west to east.
- **The Eastern Plateau Region:** This region covers the eastern half of the country. Elevations decrease from 1 200-1 800 m at the major watershed lines to 900 m on the northern desert border and to sea level on the coast. The climate in general is hot and dry, with average annual rainfall below 100 mm, except in the higher parts. Nevertheless, floods following rare rainfall may be devastating.
- **The Desert:** Between the Yemen Mountain Massif and the Eastern Plateau lies the Ramlat as Sabatayn, a sand desert. Rainfall and vegetation are nearly absent, except along its margins

where rivers bring water from adjacent mountain and upland zones. In the north lies the Rub Al Khali desert, which extends far into Saudi Arabia and is approximately 500 000 km² in area. This sand desert is one of the most desolate parts of the world.

- **The Islands:** The most important of all the islands is Socotra, where more exuberant flora and fauna can be found than in any other region in Yemen.

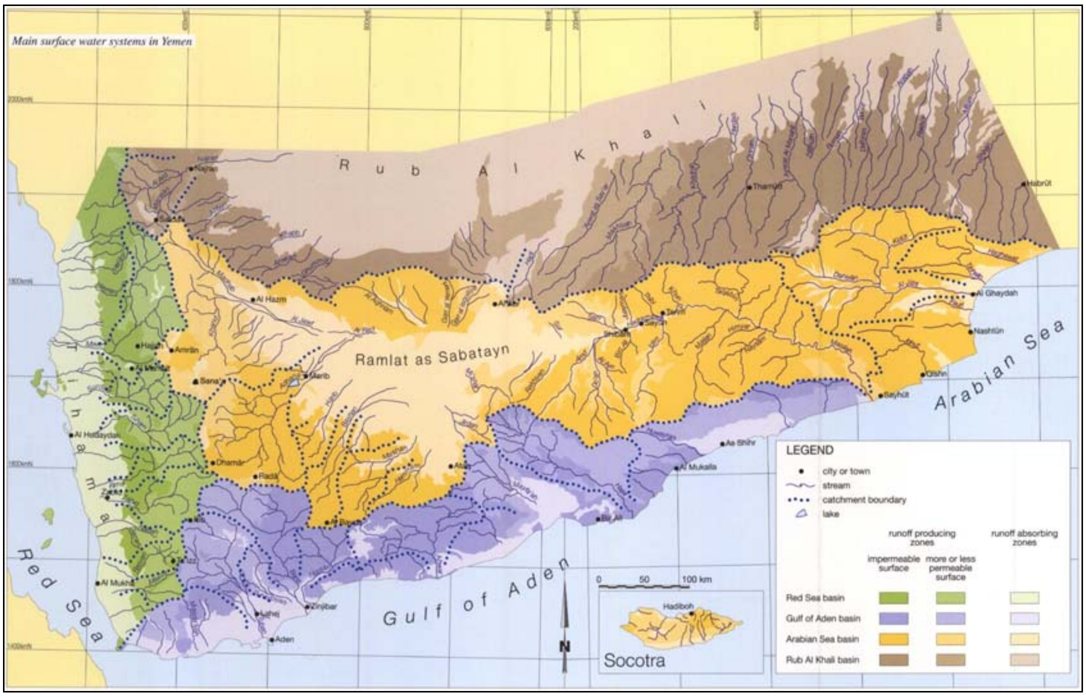

Fig. 3 Main geographical/ climatological regions (Van der Gun, 1995)

Rainfall: The climate of Yemen is strongly influenced by the mountainous nature of the country (van der Gun, 1995). Rainfall rises from less than 50mm along the Red Sea and Gulf of Aden coasts to a maximum of 500-800mm in the western highlands and decreases steadily to below 50mm inland (Figure 4).

The rainfall depends on two main mechanisms, the Red Sea Convergence and the Monsoonal Inter tropical Convergence Zone. The former influence is most noticeable in the west of the country, this is active from March to May and to some extent in autumn, while the latter reaches the country in July-September, moving north and then south again so that its influence lasts longer in the south. Seaward exposed escarpments such as the western and southern slopes receive more rainfall than the zones facing the interior. The average temperature decreases more or less linearly with the latitude.

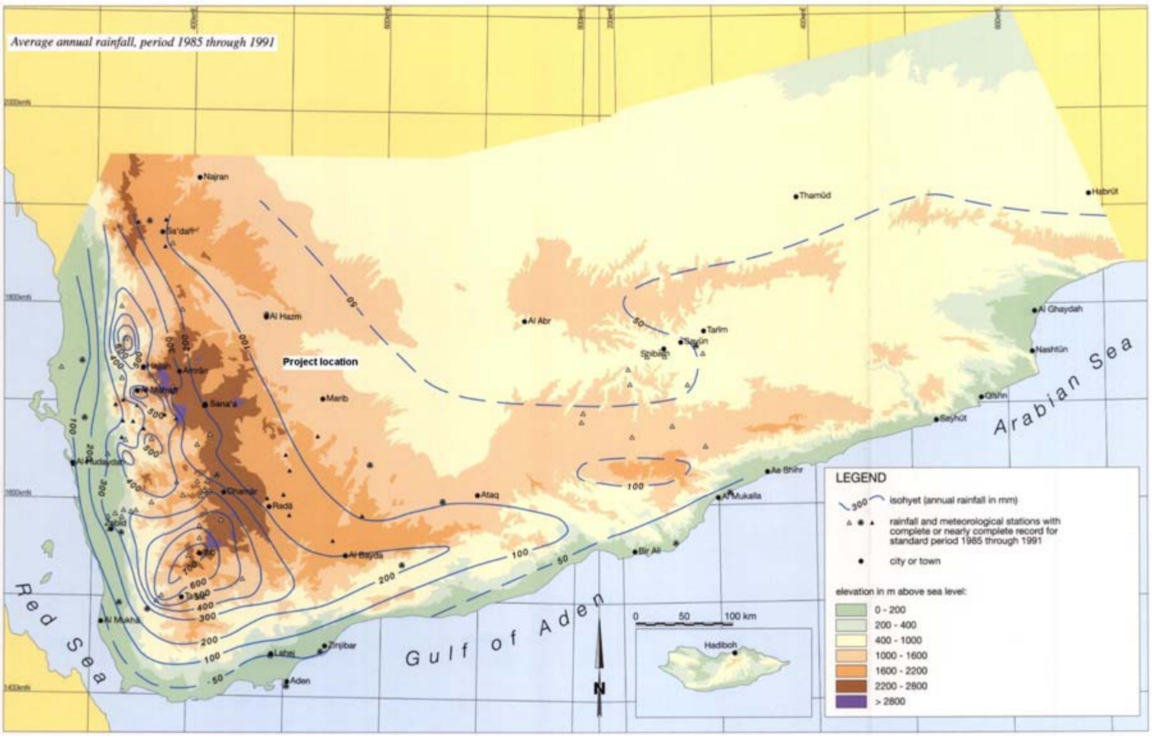

Fig. 4 Average monthly rainfall patterns for selected rainfall stations (Van der Gun, 1995)

Temperature: Average temperatures are dominantly controlled by elevation. There is an approximately linear relation, this relation is disturbed by the proximity of the sea in the coastal areas. Mean annual temperature range from less than 12.5ºC in the central highland to 30ºC in the coastal plains. However, the winter temperatures may decrease to freezing the highlands.

Evaporation and evaportranspiration: The penman method, Doorenbos and Pruitt (1984) version was used to calculate potential evaportranspiration. Table 4 presents the results in term of average annual totals. The annual totals range from 1579mm (Dhamar) and 3427mm (Al Jawf) for the meteorological stations considered. Thus factors other than average temperature must have a notable influence on the potential evaportranspiration variations. Analysis shows that quite a large part of the variation is explained by differences in wind speed, which possibly reflects local rather than regional effects.

In spite of all restrictions and inaccuracies, the data allow the following ranges for the annual Penman evportranspiration in different zones of the country to be indicated tentatively:

- Costal zones and foothills:	1800-2700 mm
- Mountain zones of Western Yemen	1500-2500 mm
- Arid zones of the interior	2000-3500 mm

Evaporation exceeds rainfall over most of the territory of Yemen this implies that except in some limited areas, soil moisture deficit prevails most of the year; evaportranspiration rates are usually far below their potential level, which my only be reached during and shortly after rainy spells. For such areas, reduction factors must be used when actual evaportraspiration is estimated from potential evaportranspiration may be close to the potential value.

Potential evaportranspiration is closely related to open water evaporation (as a first approximation it can be estimated at 70% to 80% of the evaporation rate). However, the actual evaportranspiration is substantially lower in Yemen, except in well-irrigated areas.

HISTORY OF WATER HARVESTING SYSTEMS IN YEMEN

In Yemen, ruins of dams and reservoirs as well as the unique, spectacular mountain terraces, confirm the long history of water harvesting. The great historical Marib dam and its collapse are mentioned in the Holy Koran. Recent archaeological excavations discovered ruins of irrigation structures around Marib city dating from the middle of the third millennium BC (some 4000 years ago). Farmers in this same area are still irrigating with floodwater, making the region perhaps one of the few places on earth where runoff agriculture has been continuously used since the earliest settlement (Bamatraf, 1994).

Recent studies in Yemen on water harvesting, (Tahir, 2002), indicate that villagers in the mountainous areas are well acquainted with ware harvesting systems for hundreds of years. They use the collected water for drinking, animal watering and supplementary irrigation particularly in the drier seasons. They mainly building cisterns to collect run off from clear and well selected catchment areas well away from the villages to prevent pollution. Old local manufactured material such as *Khadad* is used to cement the cisterns which proved to be of high quality and can withstand all environmental changes such as weather, rain, temperature, etc and can last longer periods. However, further research is needed on such material.

RAINWATER HARVESTING SYSTEMS IN YEMEN

Rooftop water harvesting systems

The roof water harvesting in Yemen has the advantage of being low cost, relatively simple in design (household technology), less laborious and it saves time. It provides adequate water during the rainy season, a period when the rural people are busy with farming activities. They are more appropriate in mountainous areas where there are no ground water sources, and where rainwater is the only feasible means of providing a water supply. In such areas it is difficult to think that communities can be served by a centralized water supply schemes which proved to be very expensive in terms of implementation, operation and maintenance. Other sources require long walk and time for women and children to fetch water. The quality of water is also reported as good compared to other water sources in the rural areas.

In Taiz Region, during the rainy season, roof water is collected in a dug-out structure, known as Seqaya. These structures are excavated into the hard rocks. In addition to roof water surface runoff is also collected into the hard rocks. Surface run-off is also collected into the dug-out structures for multifarious uses. In hilly areas of Al-Hujaria District, roof with provision of border-line lead pipe and outlet is common. The harvested rainwater, in turn, is guided to an underground storage tank through a settling tank for domestic use.

Terracing

Terraced mountain land in Yemen was continuously cultivated Early settlers of Yemeni mountain land faced an ambivalent situation. Rich soil derived from volcanic laves and pyroclastics were an asset, as were the spring and summer rains of the semiarid monsoonal climate. But where rainfall was highest, relief energy was also highest. With an amazing labor input, the settlers constructed millions of terraced fields on steep, rugged mountain slops and began simple, highly effective methods of harvesting rainwater (Bamatraf, 1994).

Rain water collects in the terraces and soaks into the shallow soil. Walls at the edge of the terraces prevent runoff form flowing down to the next terrace except during intense rainfall events. The walls of the terraces are built of stones, while voids between the stones allow water to move down to successive terraces without eroding the soil. Water can also move from level to level near the sloping bedrock. Subsurface drainage is required in these areas to channel flow from one terrace to the next trap fine sediment. They are designed and constructed in a manner to allow the passage of runoff through sheet flow, which prevents damage to the terraces from runoff concentrating at certain points. This method is effective if terraces are constructed in the upper parts of the wadi (see figure 5)

Fig. 5. Terraces on mountain slopes in the Yemen Highlands (Author)

Ponds

Farm ponds are small storage structures used for collecting and storing run-off water. As per the method of construction and their suitability for different topographic conditions farm ponds are classified into 3 categories, viz. Excavated farm ponds suited for flat topography, embankment ponds for hilly and rugged terrains with frequent wide and deep water courses; and excavated-cum-embankment type ponds. Selection of the location of the farm pond is dependent on several factors such as potentiality for yielding sizeable quantity of run-off, rainfall, land topography, soil type and structure, permeability/water-holding capacity, land-use pattern etc. Structurally, the excavated farm ponds could be of 3 types: square, rectangular and circular. All farm ponds must have the provision of removal of excess run-off water by providing 'drop inlet spill-way under normal condition' and 'emergency spill-way' to dispose off overflow of water after heavy rains. Such spill-way should ideally discharge into a grass waterway to avoid excessive erosion.

Cistern system

Karif or *Majel* is a local name for cistern in the mountainous area of Yemen (see figure 6). It is generally underground tank, constructed from masonry or concretes and usually covered and used for the collection and storage of surface run-off. This system of rainwater harvesting is also common in the rural areas of Botswana, Ghana, Kenya, India, Sri Lanka, Thailand and Indonesia. Water thus collected in is generally used for drinking and other domestic uses.

Fig.6 Traditional water harvesting cistern in Yemen

FLOOD WATER HARVESTING (SPATE IRRIGATION)

Flood water harvesting, known as ‘large catchment water harvesting’ or ‘Spate Irrigation’, is the simplest type of water harvesting, where cultivated areas lie within and immediately adjacent to an ephemeral stream or wadi. It is rations the occasional floodwaters form storms in the mountainous catchment areas to the coastal and foothill areas.

Traditionally, agriculture in Yemen has depended on dry farming using either rainfall or spate irrigation. Rained agriculture is practiced on terraces in most of the highlands, while spate irrigation is practiced along the wadi courses and coastal plains of Tihama and south and eastern parts of Yemen. More than 1.6 million hectares are regularly cultivated. Of the cultivated area, 50% is rain fed, 32% under well irrigation, and 18% under spate irrigation and base flow. Spate irrigation is widely used in Yemen for the production of major crops; A large portion of the cultivated area relies on spate irrigation. Figure 3 shows the irrigated area under floodwater harvesting in Yemen and other countries in North Africa and the Middle East, according to FAO (1997).

The country’s particular topographic structure affects and modifies the climate on a regional basis, especially rainfall distribution, and influences the availability of water for agriculture. The majority of Yemen consists of rugged terrain of igneous and metamorphic rock. Some areas receive rainfall in excess of 500 mm/yr. Extensive terracing is being practiced in the mountainous areas.

The hydrographic system of Yemen consists of rain fed watercourses (wadis) occasionally flooding but usually dry, draining from the main watershed along the three major escarpments. In the rugged slopes of the Western escarpment seven major wadis run toward the Red Sea, which they sometimes reach during periods of heavy rain. In the southern slopes the wadis of Tuban and Bana run, through a similar but less precipitous course, to the Gulf of Aden. Table 1 presents average of total annual flow at some selected wadi in Yemen.

Table 1. Mean catchment yield for gauged wadis in Yemen(Van der Gu, 1995)

Wadi Name	Bana	Zabid	Surdud	Mawr	Adhana	Masila	Tuban	Jaza'a
Catchment Area (km^2)	6200	4632	2370	7912	8300	22500	5060	15000
Average Annual flow (Mm^3)	169.9	125	69.3	162.3	87.5	51	109.4	60

The floods of the wadis in Yemen are generally characterized by abruptly rising peaks that rapidly recede. In between the irregular floods the wadis are either dry or carry only minor base flows. Surface water is considered to be an important source for irrigation in Yemen; it is estimated to be about 1,500 Mm^3/year. Several dams and dikes were built on many main wadis for the purpose of directing spate waters into man made spate irrigation systems. Cultivation of flood is carried out through the sources of water include either direct rainfall or flood water spate as seen in Plate 3. The flash flood, as it appears along the wadi banks, is diverted using temporary structures to small individual farmlands located along the wadi banks, and the diverted water is spread into the field as to irrigate crops.

TRADITIONAL SPATE IRRIGATION IN YEMEN

The fundamental feature of traditional spate irrigation systems in Yemen is the well-established principle which gives upstream irrigators priority rights to water abstraction over the downstream users. Once the upstream user has satisfied his needs, he has an obligation to release water downstream (Tahir et al, 1996). With traditional systems, modest and often temporary deflectors allow water to pass to lower off-takes, thus creating a perception amongst farmers, of a large degree of fairness in water utilization. During the early part of the season, one or two run-off irrigation improves the establishment of the crop stand and the last season runoff (three or four irrigation) will bring the crop to full maturity.

Spate systems are made in such a way that ideally the largest floods are kept away from the command area. Very large floods would create considerable damage to the command area. They would destroy flood diversion channels and cause streams to shift. This is where the ingenuity of many of the traditional systems comes in. Spurs and bunds are generally made in such a way that the main diversion structures in the river break when floods are too big. Breaking of diversion structures also serves to maintain the floodwater entitlements of downstream landowners. The structures can be classified as follows (Camacho, 1986).

Deflectors or (Al-Qaid): Low earthen bunds, protected with brushwood and stones from the wadi extend into the minor bed of the wadi at a acute angle to the bank (Figure 7); This structure built to divert water from the main wadi to agricultural lands in quantities proportional to the irrigated area and the size of the flood in the wadi.

High earthen bunds or (Ogma): Local farmers build an earthen bank or (Ogma) of wadi bed material across the low flow channel of the wadi, with the object of diverting the entire low stage of the spate flow to their fields. During a large spate, as there is no prevision for a spillway, the (Ogma) is either breached deliberately or it is over-topped and breaches as the flood rises. See (Figure 4).

Drop structures (Al Masaqit): These are built in spate canals when a channel has a steep longitudinal gradient, or the water is transferred from a high channel to lower one. The structure is built on a foundation of dry stone, occasionally mixed with a little concrete. The remaining part of the structure is constructed with stone interlocked properly, the gaps filled with smaller stone.

Spillways (Al Masakhil): The purpose of these structures is to control the quantities of water which enter the main spate canal. Al Masakhil is usually built on the earth embankment of the canals from medium size stone. The frame of the structure on both sides of the embankments goes down deep in to the foundation, so the supporting soil has no direct contact with the water.

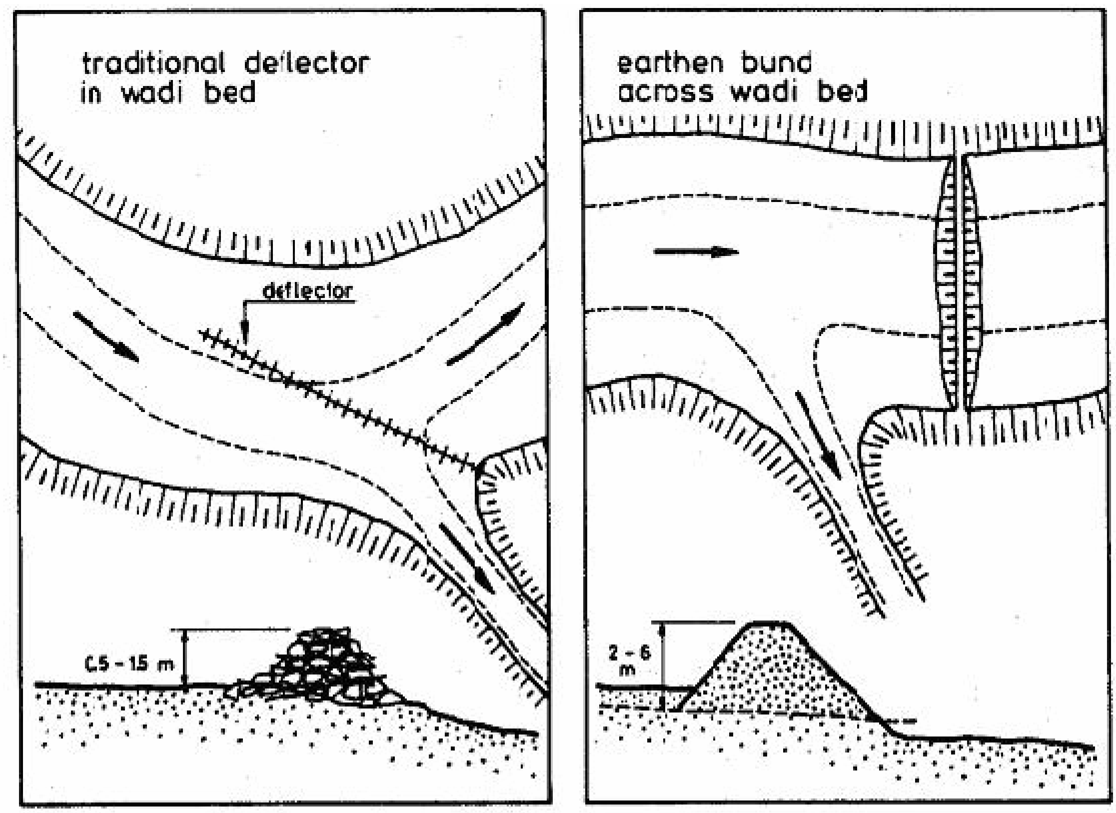

Fig 7 Schematic layouts of the traditional spate irrigation in Yemeni wadis (Oosterman, 1986)

TRADITIONAL LAW OF WATER RIGHTS

The traditional law of water rights in the mountain terraces is varying from area to area. There is one person in each area (call him AL-Moqadem), he is a local expert in these side and he know very will the area and the land owners. From the discussions with the farmers, the runoff water harvesting rights can be divided into two main parts;

- First of all when the farmer has own land as a catchments area for his terraces. He has shoos to utilize these runoff or to divert it to the down terraces. The farmer down dose not however have any legal rights to the runoff water and the farmer farther up may prevent him from receiving it.
- Secondly, when the farmers chare one catchments area together, for example natural rocky mountain; this catchments area divided between the farmers based on the area of the land owners. There are diverted channels for each land, and no body can divert runoff water from the other. When the flood occurs, the farmers drain the extra water from up terraces to down until the wadi bed. The main drainage canals should repairing and maintenance with cooperation all the farmers.

The runoff diverted by canals dose not have any legal right to cross land owned by another farmer. But in some places with the signed agreement between the farmers, there is a permeation to allow the diverted canals can a cross land owned by another farmer.

FUTURE ROLE OF WATER HARVESTING

Appropriate systems should ideally evolve from the experience of traditional techniques. They should also be based on lessons learned from the shortcomings of previous projects. Above all it is necessary that the communities appreciate the systems where they are introduced. Without popular participation and support, projects are unlikely to succeed. During recent years some developments took place in regard to water harvesting which might have some impact on the future role of water harvesting in general and may expand to other areas in the world:

Supplemental water system: Runoff water is collected and stored offside for later application to the cropped area using some irrigation method. The water stored allows a prolongation of the cropping season or a second crop.

Dual purpose systems: In a dual purpose system the runoff water flows first through the crop area then the excess water is stored in some facility for later irrigation use. In Arizona, USA, runoff irrigation was combined e.g. with trickle irrigation, using sealed soil surfaces to increase runoff rates.

Combined systems: If the irrigation water from aquifers or from rivers/reservoirs is not sufficient for year-round irrigation, a combination with runoff-irrigation (during the rainy season) is feasible. The combination of runoff- and furrow irrigation is reported from North Central Mexico (Frasier 1994).

Modeling: If more information on hydrological, soil and crop parameters is available, models can be developed and applied to water harvesting for certain environments.

Soil storage: The water is being stored in the soil profile. A high storage capacity of the soil (i.e. medium textured soils) and a sufficient soil depth (> 1 m) are prerequisites here (Huibers, 1985). The water retention capacity has to be high enough to supply the crops with water until the next rainfall event.

CONCLUSIONS

The following conclusions may be drawn:

- Appropriate systems should ideally evolve from the experience of traditional techniques - where these exist. They should also be based on lessons learned from the shortcomings of previous projects.
- Above all it is necessary that the communities appreciate the systems where they are introduced. Without popular participation and support, projects are unlikely to succeed.
- With the benefit of good maintenance, the terraces will continue to supply Yemeni households with productive crops. Neglect in the more marginal areas for food production means that uncontrolled runoff of rainfall and soil erosion can cause terrace collapse and food reduction.
- The government must strengthen rain fed agriculture and traditional methods of rainwater harvesting for agricultural and domestic use must be forced. These will increase expected returns on investment, particularly for food crops, and increase the willingness of landowners to invest in projects such as terrace maintenance
- Best use of available water resources
- Water harvesting increases groundwater recharge.
- It restores the productivity of land, which suffers from inadequate rainfall by increases yields from rain fed farming and runoff water collection and minimizes the risk in drought prone areas
- Water harvesting is considered as an alternative source for irrigation which reduces the dependency on groundwater
- Encourages the application of traditional techniques with possibilities for improvement according to the conditions of the project and enhances community participation and awareness.

RECOMMENDATIONS

The following strategies are suggested for sustainable use of water harvesting:

- Focus on small-scale water harvesting schemes that are now being promoted by NGOs.
- Involve the beneficiaries in the decision-making, planning, management and use of the available resources.
- There is rich indigenous knowledge in different parts of the Arab world and they should be researched and documented.
- Farmers need scientific and institutional support to start new projects
- Sufficient attention must be given to social and economic aspects.
- Learning from failures and successes, a high degree of sustainability might be reached.
- There should be cooperation between scientists and practitioners involved in water harvesting in the Arab countries and globally.
- Equal opportunities for of women and other disadvantaged farmers
- The relation between land tenure, water rights, and the introduced technologies should be carefully considered.
- No attempt is made to make an exhaustive list of the research needs. It merely brings together some suggestions to strengthen the studies on water harvesting. Existing studies on physical relationships should be complemented by studies on economic and policy implications of investments in the rural development of marginal lands. Studies are needed:
    1. On the extent to which traditional water harvesting systems can be used as a starting point for the new WH systems, and to evaluate the possibilities for optimizing water use efficiency.
    2. For the development of crops and crop species that produce well under conditions of limited water supply characteristic of WH systems in dry lands.
    3. On the hydrological behavior of small catchments and the development of simple and reliable methods for estimating runoff efficiency under a wide range of physical conditions and for variously sized catchments.
    4. On appropriate investment policies in harsh environments, where local populations are barely able to subsist without infrastructural interventions. These studies should assess the likely benefits in terms of economic, social, and environmental effects resulting from such investments. and finally

REFERENCES

Bamatraf, M. A. (1994). “Water harvesting and conservation systems in Yemen”. FAO Proceedings of the Expert Consultation about “Water Harvesting for Improved Agricultural Production”, Water Report 3.

Camacho, R. (1986). “Traditional spate irrigation and wadi development schemes”. proceedings of the subregional expert consultation on wadi development for agriculture in the natural Yemen. Aden-Yemen.

FAO, (1997), “Irrigation in the Near East Region in Figures. *Water Report* (9).www.fao.org.

Frasier, G. W. (1994). “Water Harvesting/Runoff Farming Systems for Agricultural Production”. Water Harvesting For Improved Agricultural Production. Expert Consultation, Cairo, Egypt. 57-73.

Huibers, F. P. (1985). “Rainfed agriculture in a semi-arid tropical climate: aspects of land and water management for red soils in India”. Doctoral Thesis, Agric. Univ. Wageningen, NL.

MAI, (2000). "Agricultural Statistics Year Book".

Oosterman, J. (1986). "Diversion structure and protection works" proceedings of the subregional expert consultation on wadi development for agriculture in the natural Yemen. Aden-Yemen.

Tahir T. M. (2002) “Rainwater harvesting systems: a community based managed systems”. *Journal of Science and Technology*, (JST), 7(1), 1-8.

Van der Gun,(1995). “The water resources of Yemen”, Report WRY35, TNO, Delft.

Holistic Approach to Rain Water Harvesting in the Aravali Hills, Rajasthan India

Om Prakash Sharma[7] and W Mike Edmunds[8]

ABSTRACT

Water provision is an essential foundation for all other forms of development. Three case studies from Rajasthan, India illustrate how safe potable water availability not only improves health and releases time and energy of women, but also improves poor people's income, education, as well as social and cultural well-being. Increased water availability through small scale water harvesting structures in *Nayagaon, Jamun and Nala* villages has increased the productivity of crops, fodder and milk production. Local village self-help groups also started playing active roles in the village development issues such as education and health care. The communities are carrying out many activities themselves, enabling to take next step towards better sustainable future.

Key Words: Water harvesting, Livelihood, Poverty reduction, Health and Education.

1. INTRODUCTION

Wells for India is a UK registered Charity working with the poorest communities in Rajasthan, India. Since its inception in 1987, the Charity has been supporting rainwater harvesting as its primary intervention in community development. This work is spread over 11 districts of Rajasthan working with 22 local non-government organizations (NGOs). Projects are generally based in village clusters in the upland areas of a river basin where resources can be targeted at individual villages. Successful water harvesting intervention in one village often provides the model for adoption and replication in neighboring villages.

This paper gives an account of Wells for India's recent experiences in water harvesting works in semi-arid parts of Rajasthan, notably in the Aravali Hills. Results from a 5-year project show that, water harvesting is an essential foundation for all other forms of development in a village. Small scale water harvesting work not only helps in increasing water availability but also in enhancing productivity of food grain and fodder and allowing income generation. Local village self-help groups formed in the villages are playing active roles in the village development tackling issues such as health and education. Through water security groups are motivated to carry out a variety of activities, enabling them to take their next step towards better sustainable future.

2. PHYSICAL AND SOCIAL SETTING

Rajasthan is one of the driest states in India with annual average rainfall ranging from 100 mm in the western desert to 650 mm annually in the southeastern part of the state. Located in this arid and semi arid region of India, its 56 million people intermittently suffer moderate to severe water crisis. The Aravali hills, count among the oldest mountain ranges of the world and run across the state from southwest to northeast. The Hills covers about 30% of the state's area. The oldest rocks are granites and gneisses, overlain by Archaean sedimentary or volcanic rocks of the Aravalli Super group, Delhi Super group, the Vindhyan Super group and younger rocks. The Aravali hills influence the drainage system of the state with runoff eventually to the Bay of Bengal and the Arabian Sea.

Marked variations in diurnal and seasonal range of temperatures are characteristic of the region. In the western part, the maximum daily temperatures vary between 40°C to 48°C during summers, with 2°C to 5°C during winters. Rajasthan has a rich history of rain-water harvesting and conservation of both

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surface and groundwater has been an integral part of Rajasthan for many centuries (Agarwal and Narain 1997).

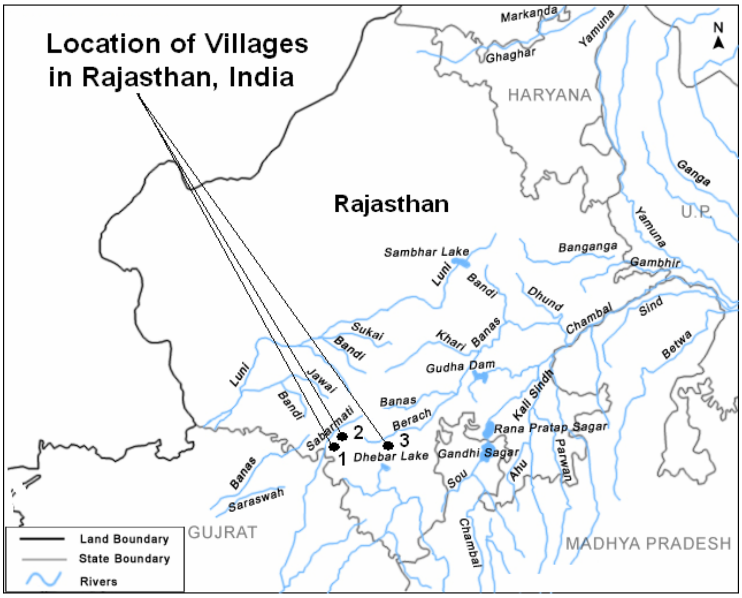


Figure 1. **Map of Rajasthan showing areas where Wells for India is working**

The regions in which Wells for India is working (Figure 1) comprise a series of small villages with a mixture of tribal people and scheduled castes. The main occupation of these tribal communities is agriculture, rearing livestock and securing small daily wages. Poverty persists in many such rain-fed and upland areas. Lack of food, fodder security and an absence of any economic activity, leads to losses of wages, unemployment and migration. Migration affects the schooling of children and forces many children to work. The problem is aggravated during drought, when people have to borrow money from moneylenders at high interest rates. This makes the poor farmers even poorer forcing a shift to wage labour. Poverty and hardship affect whole communities but to a greater extent for women who shoulder added responsibility for managing families. With depleting natural resources, women have to walk further for water, fuel wood and fodder.

Migration of the men in search of labour to nearby towns significantly increases women's responsibilities. The women who remain behind are burdened by multiple responsibilities of child-care, animal-care, care of the elderly, as well as looking after the small agricultural land holdings. The women who migrate are susceptible to physical abuse at the hands of the contractors and landowners at the place of work. Women, especially poor women, are often trapped in a cycle of ill health exacerbated by childbearing and hard physical labour.

3. HOLISTIC APPROACH TO RAIN WATER HARVESTING

Wells for India, through its local Indian NGO partners started a long term Drought Mitigation Project in the Aravali Hills in 2001 with water harvesting as the central activity. This project was designed with a premise that once the water is harvested and water availability increases in a village, it would be natural that agriculture and allied activities would follow. With time the development process broadens its base and paves the way for a wider range of activities including horticultural development, livestock development and income generating activities. Community based organizations, including Self Help Groups, and Village Development Committees were promoted and strengthened to take responsibility for the proper execution and management of the assets created

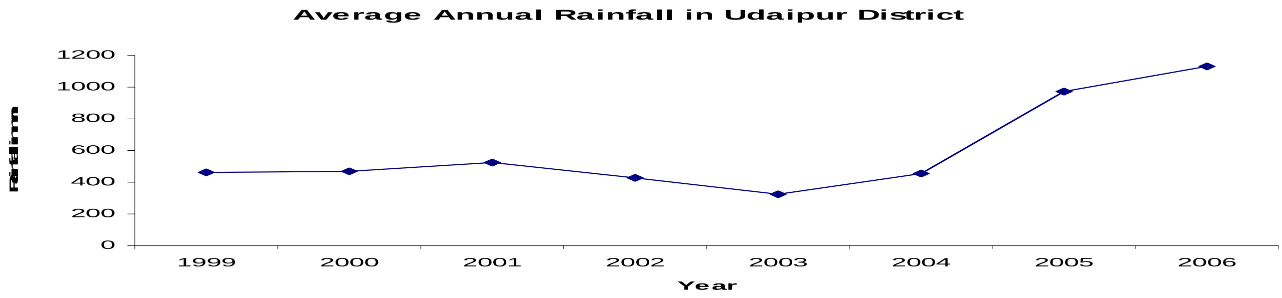
A simple scientific monitoring system to gauge the impact of water harvesting works was developed before the inception of the project. Regular monitoring of water level data in wells, crop production, income-generation were done by local villagers, following initial training by NGOs. Several locally based NGO partners and AFPRO– a leading national level agency on water harvesting provided supervisory services on data collection.

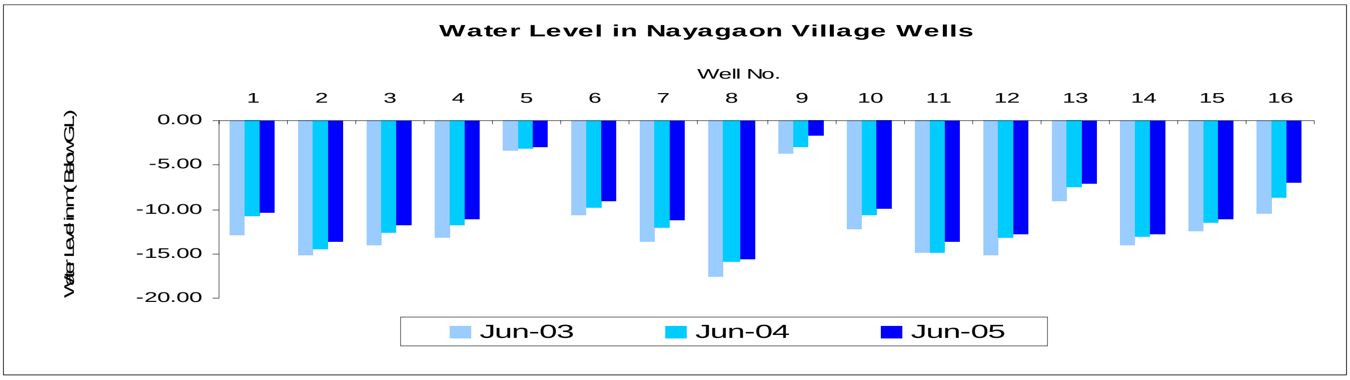
Figure 2 **Small water harvesting structures before and after rains in the Aravali Hills**

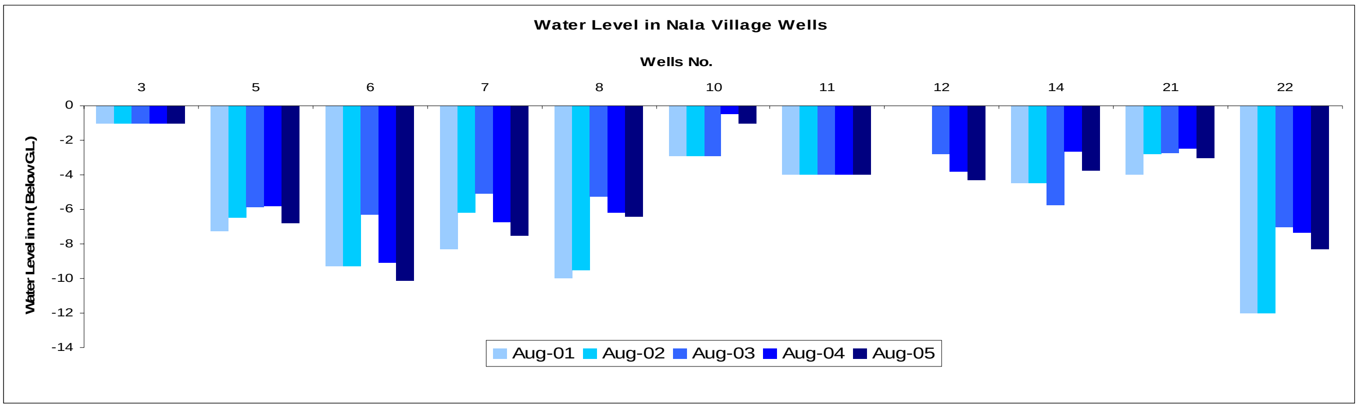
3.1 Water harvesting structures

Construction of loose boulder gully plugs, field bunds, contour trenches, farm ponds, percolation ponds, subsurface dams and small masonry structures was carried out in selected catchments, thus treating whole areas of the landscape. Construction of such water harvesting works was carried out by local villagers themselves. During the construction of these structures villagers contributed 20 % of the labour cost (Figure 2).

3.2 Impacts of structures with increased availability and accessibility







- Water level monitoring was carried out in each of three villages quarterly over a five year period and covered the pre and post monsoon periods. An increase in groundwater levels in the villages (Figure 3) resulted in easier access and availability of water for drinking and irrigation purposes. Rising water levels coupled with some well deepening helped in increasing water column in wells, and therefore water availability period, water generally being available throughout whole year.. The average water column reported as 3-fold increase as compared with the pre-project implementation situation. The data indicate:
- that the average water column increases from 2 to 5 m.
- The distance of source of drinking water for the villagers (primarily women –who are the major collectors of water in a family) has reduced from average 1000 m to 200 m
- The time and energy for collection of water has reduced, leading to increased energy and time for other gainful activities.
- Water restoration work has also enabled easy accessibility of drinking water for the cattle.

3.3 Improved food grain and fodder availability

- Increased water availability resulted in increased availability of water for irrigation and subsequent increase in area of primary (monsoon) and secondary winter crops (Table 1). There is a visible increase in pumping times from an average of 30 minutes during 2001 to more than 2 to 3 hrs, after completion of water harvesting works during 2005.
- The increased availability of water in each village has led to increasing interest and uptake by the farmers in agricultural activity. Many migrant youths returned back home during the project period and began paying attention towards improving their land and water resources for sustainable living.

Table 1. Monsoon and winter (rabi) crop production over a five-year period in Nayagaon and Jamun villages

Monsoon Crop area and Production in Nayagaon village			
Year	**No of farmers**	**Area in Hectare**	**Production In Kilogram**
2001-2002	40	38	266
2002-2003	60	63	670
2003-2004	79	70	775
2004-2005	101	92	1104

Winter Crop area and Production in Nayagaon village			
Year	**No of farmers**	**Area in Hectare**	**Production In Kilogram**
2001-2002	7	5	25
2002-2003	35	15	137
2003-2004	46	19	237
2004-2005	60	25	375

Monsoon Crop area and Production in Jamun Village		
Year	**Area in Hectare**	**Production In Kilogram**
2000-2001	23.71	5244
2001-2002	32.53	7097
2002-2003	23.29	5153
2003-2004	25.54	5652
2004-2005	27.95	6187
2005-2006	27.33	6046

Winter Crop area and Production in Jamun Village		
Year	**Area in Hectare**	**Production In Kilogram**
2000-2001	5.50	7390
2001-2002	0	0
2002-2003	1.97	2773
2003-2004	2.95	4689
2004-2005	15.69	21167
2005-2006	24.00	26697

- The "agricultural revolution" in the villages also led to improved health situation among the women and children.

3.4 Reducing poverty and enhancing livelihood opportunities

- Prior to the water harvesting work the villagers did not undertake cultivation of vegetables due to lack of irrigation facilities. However at the present time around 60% of the families are undertaking vegetable production. The vegetables are first used for household consumption and any surplus then sold in the village or in the market. Table 2 shows the income of 18 families of Nala village due to vegetable gardening.

Table 2. Increased incomes over the period 2001-2005 for villagers in Nala village, Aravali Hills

Sl	**Name**	**Annual income in INR from Vegetable Gardening**				
		2001	**2002**	**2003**	**2004**	**2005**
	Total	800	10,400	72,400	98,300	124,900
	Per family	400	742.86	5171.43	6143.75	6938.89
	Families	2	14	14	16	18

"I never grew vegetables in my field earlier. After increased water availability in my well, I started growing different vegetables such as brinjal, bhindi, tarohi, loky, from 2002 onward. At present I have a vegetable plot of 0.1 hectare from which I could earn Rs. 1100 by selling vegetables. Earlier we used to take only chapatti (local bread) with dal (pulses) only, but now my family is enjoying the flavour of green vegetables in the food intake."

Sankalal Gulaji, Nayagaon

3.5 Improving gender equity and sustainability

- Self-help Groups (SHG) formed a platform of women empowerment - especially for the tribal women of the village who were always treated as subordinate to men in the patriarchal society. SHGs are active people's institution formed in the villages. The formation of these SHGs, consisting typically of 20 women members followed an initial discussion of the importance of getting together and having a unified voice. Overall increased water availability and accessibility, followed by subsistence agriculture gave dignity to these poorest communities. This is very well said by Ambavi Bai w/o Kesa of Nala village:
- *My house is located on high elevation. I used to walk to someone else's well, located 1.5 km from my house. But due to some problem during 2001 they did not allow me and my cattle to drink water. They used to tease me that if you are young why not dig a well yourself and take water. My husband and I started a well and could not complete it. The Project helped us in further deepening and recharging it through water harvesting works. This has helped me in regaining my pride and of course eliminates my travel of 3 Km daily.*

Table 3. The status of self help groups in Nayagaon, Jamun and Nala villages by December 31st 2005

Village	**Total SHGs**	**Total Member**			***Total Saving (Rs.)***
		Male	**Female**	**Total**	
Nayagaon	4	57	35	92	7,613
Jamun	2	0	25	25	54,444
Nala	5	37	20	57	17,554

4. TOWARDS A SUSTAINABLE FUTURE

- After 5 years the project has provided enough support to enhance the capacity of the community members and NGOs in areas such as agricultural development, livestock management, land & water resource management, forestry & pasture management, project planning, and also to increase awareness on health, education, gender-related issues availability of support from government. schemes and programs. . Capacity building through awareness, exposure, training programs have helped in proper management of programmes and also ensured sustainability beyond the primary project lifetime.
- In addition to capacity building and empowerment of the local institutions, the project has also recognised that sustainability of a community and their livelihoods is always dependent on its linkages with various other institutions. In the absence of other effective linkages with government and other resource agencies it is difficult to sustain the initiatives. Capacity building of NGOs and community organisations helped in accessing different government programmes to the project villages, such as:
    - With local banks for financial assistant to SHGs as loans,
    - With agriculture departments for training, supply of improved seeds and agriculture implements
    - With veterinary departments for treatment and vaccination of livestock,
    - With the forestry department for development of forest land and
    - With education and health departments.

The different activities carried out in the project villages in addition to the project interventions are given in Table 3.

Village	Work Done
Nayagaon	Construction of a community hall, local village development committee executed the work. Road constructed under drought relief programme supported by the government. Hand pumps repaired with the help of government department.
Nala	VDC liaison with government education department and started a Primary school in the village. VDC also mobilized resources for installation of Solar Lights for 63 families from Tribal Area Development Agency – TADA. Village Forest Protection and Management Committee is recognized by department of Forest and is actively involved in the promotion of JFM programme. Villagers and VDC effectively mobilized construction of 4 km road up to their village. Protection wall constructed in the forest land of 50 hectare.School play ground is constructed at School

5. LESSONS LEARNED AND CHALLENGES

- The holistic approach to water harvesting provides an opportunity to advance progress on 5 of the eight Millennium Development Goals (MDGs 1, 2, 3, 4 and 7).
- Participation of community with a sense of ownership is very much essential for smooth facilitation of the program and to achieve the desired outcome. The sustainability of resources created under the project has solely depended on the degree of community participation.
- Availability of sufficient and proper baseline data is very much required to assess the impacts of project interventions at the end of project tenure. Further, proper monitoring tools such as process documentation, photography, maps, formats need to be introduced from the very beginning of the program implementation for periodic assessment of impacts as well as to measure the outcomes scientifically and in an authentic manner.

REFERENCES

Agarwal, A., Narain, S. 1997. Dying wisdom. The fall and potential of India's traditional water harvesting systems. Centre for Science and Environment. Delhi

FAO, 1999, Water for Food. Approach Paper.

Government of India. Harayali : Guidelines on Integrated watershed Management.

Government of Rajasthan : Water Resource vision 2045.

Prinz D., Anupm S.1999. Water Resources in Arid regions and their sustainable Management.

UNDP.2003. Mainstreaming Gender in Water Management.

Wells for India, 2001. Project document : Aravali Hills: Drought Mitigation Programme (2001-2006)

Wells for India, 2003. Mid term review document of Aravali Hills Drought Mitigation Programme.

Wells for India, 2006. Final Completion report of Aravali Hills Drought Mitigation Programme.

Rainwater Harvesting in Cholistan Desert: A Case Study of Pakistan

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Abstract

About 70 million hectares of Pakistan fall under arid and semi-arid climate including desert land. Cholistan is one of the main deserts covering an area of 2.6 million hectares where water scarcity is the fundamental problem for human and livestock population as most of the groundwater is highly saline. Rainfall is the only source of freshwater source, which occurs mostly during monsoon (July to September). Therefore, rainwater harvesting in the desert has crucial importance. The Pakistan Council of Research in Water Resources (PCRWR) has been conducting research studies on rainwater harvesting since 1989 in the Cholistan desert by developing catchments through various techniques and constructing ponds with different storage capacities ranging between 3000 and 15000 m^3. These ponds have been designed to collect maximum rainwater within the shortest possible time and to minimize seepage and evaporation losses. As a result of successful field research on rainwater harvesting system, PCRWR has developed 92 rainwater harvesting systems on pilot scale in Cholistan desert. Each system consists of storage reservoir, energy dissipater, silting basin, lined channel, and network of ditches in the watershed. The storage pond is designed to collect about 15000 m^3 of water with a depth of 6 m. Polyethylene sheet (0.127 mm) on bed and plastering of mortar (3.81 cm) on sides of the pond was provided to minimize seepage losses. All these pilot activities to harvest rain have brought revolution in the socio-economic uplift of the community. These activities have also saved million of rupees during the recent drought. Large scales adoption of all these interventions would ultimately help improve the socio-economic conditions of the residents of hyper arid area of the country.

1. INTRODUCTION

Pakistan has 70 Mha arid and semi-arid lands that is about 80% of its total geographical area (PADMU, 1983). Out of 41 Mha arid area, 11 Mha falls under main deserts where climate is hyper arid (Kahlown and Majeed, 2004). These deserts are: Cholistan (2.6 Mha), Thal (2.3 Mha), Thar (4.3 Mha) and Chagi-Kharan (1.8 Mha) (Figure 1). The Cholistan is a big desert in the Punjab province which consists of sand dune, sandy soil, loamy soil, and saline-sodic clayey soil. Human population in the desert is about 0.11 million and livestock population is nearly 2.0 million. The population is scattered at different places on the availability of drinking water. Low and sporadic rainfall (166 mm average annual), high temperatures (up to 55^0 C in summer), low humidity, high rate of evaporation and strong summer winds are the main characteristics of the climate. The groundwater is mostly saline and unfit for human and livestock drinking (PCRWR, 2004a). Because of these limiting factors, the local population is nomadic and remains in search of water and fodder for their animals.

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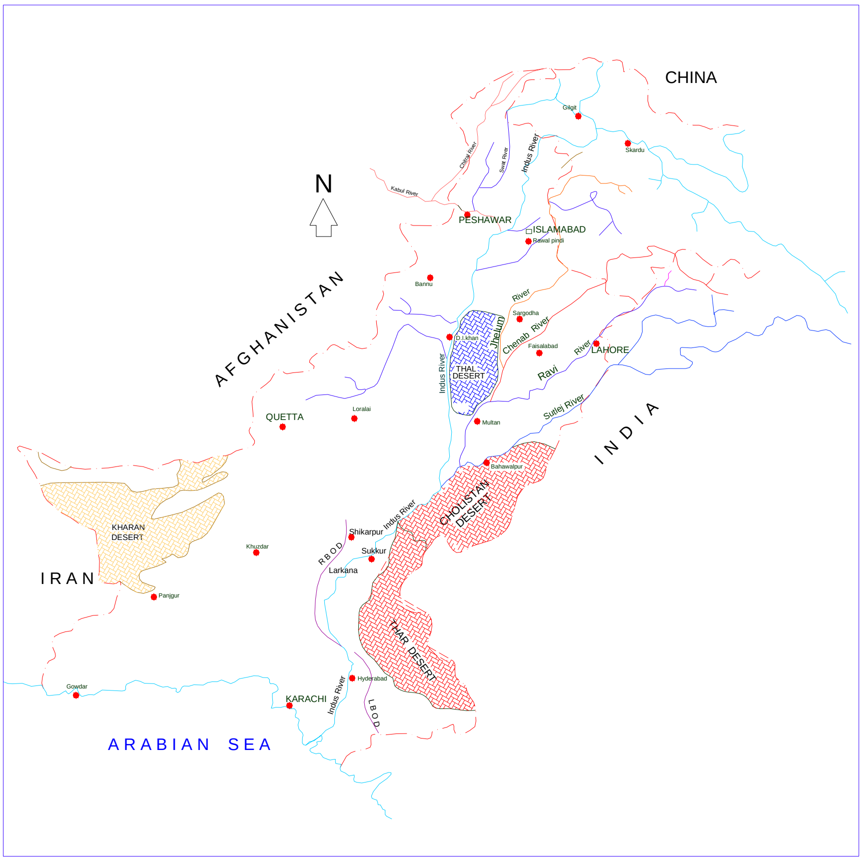

Figure 1: Main Deserts of Pakistan

The primary source of freshwater in the Cholistan desert is rainwater, which is collected in natural depressions or man-made ponds locally called *tobas*. There are more than 1500 *tobas* in the desert out of which only 500 are in operation (PCRWR, 2004b). These *tobas* are mostly not in appropriate places because the sites have not been identified based on scientific information. Most of the rainwater collected in the *tobas* is lost through seepage and evaporation due to high infiltration rates in sandy soil and temperature with strong winds during summer season. Siltation in *tobas* is another serious concern, which reduces their storage capacities rapidly, especially during monsoon season. In order to improve the situation, PCRWR has been actively engaged in various research and development (R&D) activities to uplift the socio-economic conditions of the dwellers.

Rainfall is single source of freshwater in the desert. It has been investigated that there is about 350 million cubic meter (Mm^3) runoff potential available for storage in the desert (Table 1). Results of the research studies conducted at Dingarh Station showed that drinking water requirements of the dwellers could successfully be met through collecting rainwater on scientific grounds.

Table 1: Potential Runoff in the Cholistan Desert

Year	Rainfall (mm)	Potential Runoff (mm)	Runoff for Storage in Cholistan (Mm^3)
1989	84.2	38	168
1990	144.1	42	187
1991	173.0	87	385
1992	231.0	115	506
1993	155.9	89	392
1994	299.2	152	672
1995	213.0	131	582
1996	152.0	81	359
1997	201.0	74	327
1998	172.1	65	287
1999	20.8	3	14
2000	126.4	62	273
2001	148.6	50	222
2002	2.0	-	-
2003	240.0	106	467
Average	160.5	79	350

2. DEVELOPMENT OF WATER HARVESTING SYSTEM

As a result of field research on rainwater harvesting techniques, PCRWR has initiated a 4-year Research and Development (R&D) Programme in 2001 to make water available in the desert for drinking. The activities were undertaken including reconnaissance survey to identify the suitable catchments, demographic survey to assess water demands, hydrological studies to assess the runoff potential of the catchment, topographic survey to determine the slope for runoff; development of catchments to establish a network of ditches, soil profile investigations to determine physical and chemical properties of the catchment/pond, design analysis of rainwater harvesting system to estimate the quantity of civil works.

3. COLLECTION OF RAINWATER

Alive to the problems faced by the population in the desert, 92 rainwater-harvesting systems have been developed on pilot scale. Each system contains the components like storage reservoir, energy dissipater (stair), boundary wall, silting basin, lined channel, and ditches network in the catchment. The storage pond is designed to collect about 15000 m^3 (4.0 US million gallon) of water. The depth of the pond is 6 m. Polyethylene sheet (0.127 mm) on bed and plastering of slag mortar (3.81 cm) mixture of clay, quick lime, wheat straw and cement on sides of the pond have been provided to minimize seepage losses. The quantity of the mortar for one pond includes 6 m^3 clay, 100 kg lime, 970 kg wheat straw, and 0.06 m^3 cement. The energy dissipater having dimensions of 1 m wide and 23 cm each length and height along one side of the pond protects the sides and the bed of the pond from severe erosion expected from gushy water. Boundary wall does not only restrict the wild animals and livestock but also provides barrier against movement of sand by strong summer winds. A small silting basin controls the entrance of heavy sediments and debris in the pond. Each pond has been connected with the catchment through a lined channel, which has a network of ditches. It has been observed that all the constructed ponds got fill up to their full design capacity during the rainy seasons (winter or monsoon). Water quality analysis of the selected ponds illustrated that the water quality was within the permissible limits excluding turbidity level. In general practice, the livestock drink water from the pond directly. However, the dwellers keep this water in mud pot for few hours by adding alum treatment before drinking.

4. IMPACTS OF THE RAINWATER HARVESTING PROJECT

All these pilot activities have brought about revolution by creating awareness among the desert people and the concerned development agencies working in the area. This project has harvested about 368 million gallons of freshwater annually to meet drinking water requirements of human and livestock population. Moreover, this project has saved 6000 million rupees per drought in the form of livestock production due to reduction in livestock migration, mortality, diseases and damage of crops. Increase in production of livestock has also been observed in the form of meat, milk and other utilities besides reduction of migration of human and livestock from desert towards irrigated area.

5. CONCLUSIONS AND RECOMMENDATIONS

Following are conclusions and recommendations:

(i) Out of 350 Mm^3 of runoff potential, 1.35 Mm^3 has been harnessed successfully through scientifically designed 92 pilot rainwater harvesting systems. The remaining potential can easily be exploited through adopting rainwater harvesting strategy developed and tested by PCRWR;

(ii) About 368 million gallons of freshwater is economically made available through out the year against. However, maintenance of the system by local people is recommended to make it sustainable;

(iii) There is still need to carry out research endeavors to evolve the cheapest method for reducing evaporation and seepage losses from the ponds.

REFERENCES

Kahlown, M.A. and A. Majeed, 2004, Pakistan water resources development and management. Pakistan Council of Research in Water Resources.

PADMU, 1983, Country report Pakistan - Desertification problems, extent and remedial measures. Pakistan Desertification Monitoring Unit (PADMU), Islamabad.

PCRWR, 2004a, Research study on evaluation of impact of research and development projects implementation on desertification in Cholistan. Final Report. Pakistan Council of Research in Water Resources (PCRWR). Publication No. 129.

PCRWR, 2004b, Pre-project socio-economic analysis of 25 selected settlements in Cholistan desert. Pakistan Council of Research in Water Resources (PCRWR). Publication No. 130.