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Sustainable Systems of Water Harvesting in Arid Regions, A Case Study: Sinai Peninsula – Egypt

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Abstract

Water throughout the world is getting more serious attention. Pollution, over consumption and poor water management are decreasing the quantity and deteriorating the quality. Productively per unit of water has still remained low in many areas of the world in general and in developing countries in particular. Rain is the first form of water that we know in the hydrological cycle, hence is a primary source of water. Due to the limited water resources and the rapid increase of population in Egypt and their high concentration in the Nile valley and the Delta where the River Nile and groundwater are the main source of water, the Egyptian Government has implemented great efforts to develop new settlements and communities in Sinai. Therefore, growing awareness of the potential of rainwater harvesting (RWH) for improved water resources management arose in such arid regions where collected rainwater can be stored for direct use or can be recharged into the groundwater.

In arid and semi-arid regions, such as Sinai Peninsula's wadis, the precipitation is low or infrequent during the dry season, it is necessary to store the maximum amount of water during the wet season for use at a later time, especially for agricultural and domestic water supply. Rainwater harvesting (RWH) is a method of inducing, collecting, storing and conserving local surface runoff for agricultural production, domestic uses and ground water recharge. The rainfall occurs during short spells of high intensity, then most of the rain falling on the surface tends to flow away rapidly, leaving very little for the recharge of ground water. This highlights the need to implement measures to ensure that the rain falling over a region is tapped as fully as possible appropriate through water harvesting for provide drinking and irrigation water and recharging the ground water aquifers.

This paper presents an evaluation for the current water resources, social and economic conditions. Generalized strategies have been also developed for Sinai Peninsula representing the sustainable development through the evaluation and optimal utilization of Sinai water resources. It was also found that there is a significant use of water conservation and harvesting for crop production. As a result of the hydrological studies, some promising areas were determined according to its water resources potentialities. Some water harvesting projects as detention dams were designed and constructed and some others still under studies in the south of Sinai.

Introduction

Rainwater harvesting (RWH) is defined as a method for inducing, collecting, storing and conserving local surface runoff for agriculture in arid and semi-arid regions. Catching rainwater when and where it falls for use during non-monsoon months is called rainwater harvesting. This can be done in two ways: as surface water by diverting the rainwater into tanks, ponds etc. or as ground water by ingesting it into the soil. Water harvesting is capturing and storing rainfall to irrigate plants or to supply people and animals.

Commonly used systems are constructed of three principal components; namely, the catchment area, the collection device, and the conveyance system. Water harvesting can be undertaken through a variety of ways: Capturing runoff from local catchments; Capturing seasonal floodwaters from local streams; and Conserving water through watershed management. Rainfall has four facets. Rainfall induces surface flow on the runoff area. At the lower end of the slope, runoff collects in the basin area, where a major portion infiltrates and is stored in the root zone. After infiltration has ceased, then follows the conservation of the stored soil water.

The techniques of RWH can serve the following purposes: Provide drinking and irrigation water; Increase groundwater recharge; Reduce storm water discharges and urban floods; Replenishes the ground water table and enables the dug wells and bore wells to yield in a sustained manner; and Reduce seawater ingress in coastal areas.

Water harvesting systems have been successfully utilized by people in some parts of the world where water shortage exists. The application of water harvesting techniques although potentially high is still actually low in practice. In order to meet the water demand for various purposes, sustainable systems of water harvesting and managing should be developed. Local approaches and indigenous experiences have to be encouraged and be applied easily at both village and household levels.

Basic Technical Criteria

A water harvesting scheme will only be sustainable if it fits into the socio-economic context of the area and also fulfills a number of basic technical criteria:

SLOPE: The ground slope is a key limiting factor to water harvesting. Water harvesting is not recommended for areas where slopes are greater than 5% due to uneven distribution of run-off and large quantities of earthwork required which is not economical.

SOILS: Should have the main attributes of soils which are suitable for irrigation: they should be deep, not be saline or sodic and ideally possess inherent fertility. A serious limitation for the application of water harvesting is soils with a sandy texture. If the infiltration rate is higher than the rainfall intensity, no runoff will occur.

COSTS: The quantities of earth/stonework involved in construction directly affects the cost of a scheme or, if it is implemented on a self help basis, indicates how labour intensive its construction will be.

The catchments systems used in the RWH are those where runoff is concentrated, stored and productively used by plants. The coefficient of runoff depends upon the shape, size, soil condition, temperature and geological conditions of the area of the catchment. In summary RWH may occur naturally or by intervention. Natural RWH can be observed after heavy storms, when water flows to depressions, providing areas for agriculture. RWH by intervention involves inducing runoff and either collecting it, or directing it, or both, to a target area for use. Figure (1) gives a classification of water harvesting techniques

(Printz, 2000) and (Naser, 1999), and Table (1) summarizes the main rainwater harvesting techniques. The technology and experience gained has now reached the point where some form of water harvesting system can be designed to fit within the physical, climatological and economic constraints of almost any dry region of the world.

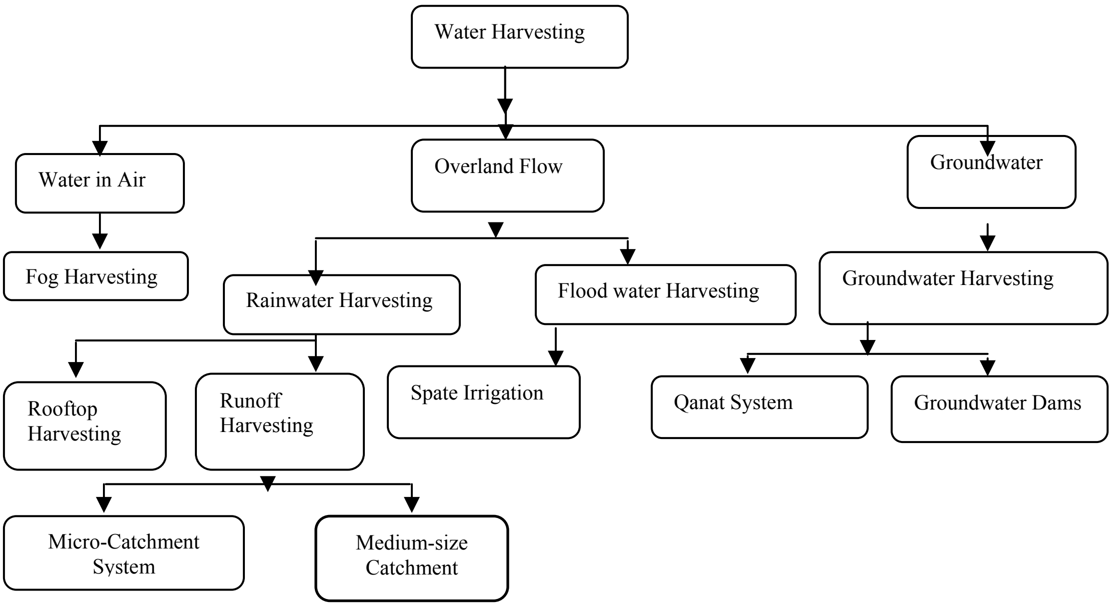


Figure (1) Classification of water harvesting techniques.

Table (1) : The Main Rainwater Harvesting Techniques in Arid Regions.

Water Source	Objectives	Water Harvesting Techniques
Rainfall	- To increase rainfall effectiveness - To conserve water and soil	Terraces Contour-ridge terracing Dams
Local Runoff	- To collect water - To store harvested water	Micro-catchment Cisterns
Wadi Flow (Flood and Base Flow)	- To protect land against flood	Earth dykes (spate irrigation and small-head pumps & earth canals) Wadi–bank enforcement
Spring Water	- To deliver water to participants within water rights limits - To store limited quantities forr short periods	Earth canals, Cisterns
Groundwater	- To abstract water from shallow aquifers - To exploit ground-water stored in the coastal sand dunes.	Shallow dug wells and pits, Galleries

General Practices of Rainfall Harvesting

Rainfall can provide considerable water resource in humid and semi arid regions. There are several techniques worldwide depending upon rainfall intensity, duration, frequency and seasonality. Brief review of such practices is;

1. Rainwater collection, this is mainly roof water collection in countries where conventional water resources are extremely scarce and each drop of rain has a real value. The ready availability of some form of roof sheeting and innovative ideas for water storage have made roof water a serious water resource consideration. Storage containers (jars) are used by householders from concrete to hold volumes 100 to 3000 lit., and measures may be needed to keep insects away. This is mainly for domestic uses.

2. Terracing, is used to collect water for two purposes, a- the horizontal surface reduces runoff and maximizes the infiltration of water into the soil. If the soil surface is kept free of vegetation except for the desirable crop, almost all rain falling on the terrace will be used for crop growth. If there are several terraces down a hill slope it may be possible to grow a crop on alternate terraces each year. b- terraces can be used as temporary water storages to reduce flow velocities of surface water and prevent erosion. The slow flowing water may be directed into a storage facility. Terracing help to provide silt free water for storage.

3. Small dams, are used (or even low embankments) across floodways, to increase aquifer recharge. Also, after rain events, it can increase soil water to become available to crop roots. A major difficulty in management of small water supply dams is sedimentation. If no attention is given to sediment control most small headwater dams will fill with sediment within a few years. There are several measures such as protect human activity upstream, sediment trap…etc.

4. Runoff enhancement is a technique used in places of water scarcity where the availability of water needs to be increased by partially sealing the soil surface. It can be done by applying surface sealing materials or by compacting the soil surface, which may be long lasting. Natural soil compaction reduces significantly infiltration characteristics and provide up to 80% of all rainfall from a storm runoff. Water can be gathered from a semi sealed surface to flow towards a tree or small vegetable plot to infiltrate to the plant root zone.

5. Runoff collection, the idea is, if large number of very small stream channels can be captured in a small channel and diverted to a different location to fill an excavated hole or small dam, then it is possible to prevent evaporation losses.

6. Flood spreading, some advantage can be gained from large torrential flows by spreading across flat areas if water is retained on flat surfaces the upper soil layer may become saturated, or water may percolate to replenish the aquifer, hence harvested water can be used.

7. Water holes and ponds, natural water holes and ponds can be exploited for water supply purposes. There is a need to ascertain the source of the water, if it is fed by groundwater or by small surface flows following each rainfall event? If the source is groundwater, the pond can be treated as a well, and increasing abstraction by deepening and increasing the hydraulic gradient towards the pond. If the surface water is the source, then an embankment could be raised across the stream bed downstream the water hole to increase the volume of water captured during rain storm. It must be realized that in areas of high potential evaporation, depth of water is the key to effective water storage.

8. Tanks, are usually constructed water container, it is fabricated from steel sheets, concrete or plastic. Their particular importance when water resource is very limited and needs to be protected from evaporation and/or contamination. Hence, it is very important to allow water to be removed from the storage tank only via a valve outlet and never ever by manual means. Commercially small capacity tanks range from 1000 lit. to 10 million lit., which can be totally closed and extremely minimum losses.

These different techniques not all will match conditions of each country, therefore, it deemed important to consider each individual country, identify its clear objectives and select the applied research to comply with the local conditions after diagnostic analysis is made. The case in semi-arid regions may require different techniques, as in Egypt. But, since the effective rainfall is not sufficient, supplementary source is required, such as saline water desalination.

Proper Design Methodology of RWH project

Throughout the globe there is a growing awareness of the potential of water harvesting for improved crop production and domestic and livestock water supply. However, most water research studies are directed towards improving runoff yield from treated catchments surfaces. Appropriate design systems should be based on the traditional techniques and experiences avoiding shortcomings of previous projects. The following points are very important for any successful project:

- Planning of overall work.
- Identification, reconnaissance, field data collection, and necessary information.
- Feasibility study, where the project will be examined and verified to be technically and economically feasible as well as environmentally sound and socially acceptable. Above all it is necessary that communities appreciate the design systems introduces. Without popular participation and support, projects are unlikely to succeed.
- Detailed design, where final engineering and allied fields study and specification is prepared with complete report and working drawings on investigation, engineering, features, environmental consideration and irrigation system.
- Physical implementation, where pertinent development have been completed.
- Beneficiaries' institution to manage and run the project.
- Government should assist the end users by providing them by agricultural extension services, maintenance & up keeping facilities and training.

Arid and Semi Arid Water Harvesting

All rainfall harvesting systems have three components: a collection area, a conveyance system, and a storage area. In this application, collection and storage is provided within the landscape; topographic depressions which represent ideal collection and storage areas as shown in Figure (2). In many situations, such areas are impermeable, being underlain by clay soils that minimize infiltration. The concentrated , stored and productively used runoff of such catchment systems in the RWH can be worked out by one of the hydrological models (e.g. HEC-1), or the simple formula of the Rational Method as follows: $Q = C * I * A$, Where: Q = Discharge m^3/time, C = Coefficient of Runoff, I = Total annual rainfall in m, A = Catchment area in Km^2.

In arid and semi-arid regions, such as Sinai' wadis, the precipitation is low or infrequent during the dry season, it is necessary to store the maximum amount of rainwater during the wet season for use at a later time, especially for agricultural and domestic water supply.

Figures (2): Rainfall harvesting system at the landscapes and topographic depressions.

One of the methods frequently used in rainwater harvesting is the storage of rainwater in sub-surface reservoirs which is called cistern. Figure (3) shows the locations of the cisterns in the North-East part of Sinai. Topographically low areas are ideal sites for harvesting of rainfall which has been used primarily for domestic and irrigation purposes. Figure (4) shows also two main techniques of rain water harvestings, these are: Storage of rainwater on surface for future use, and Recharge to ground water.

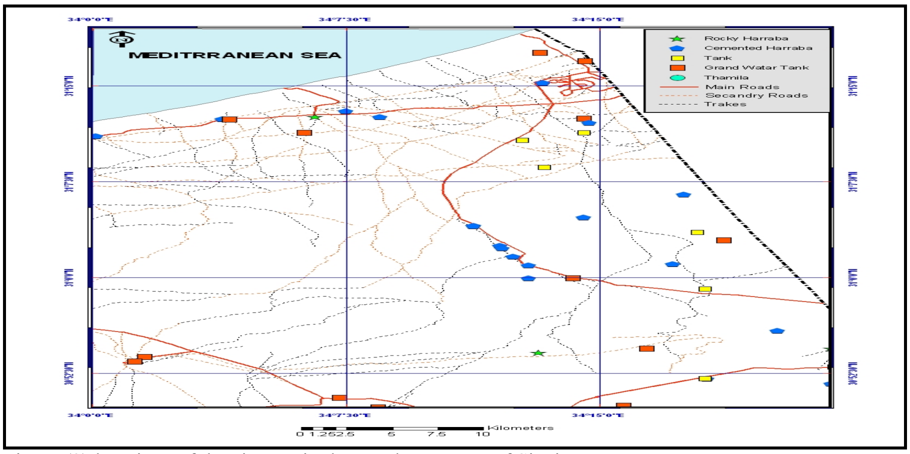
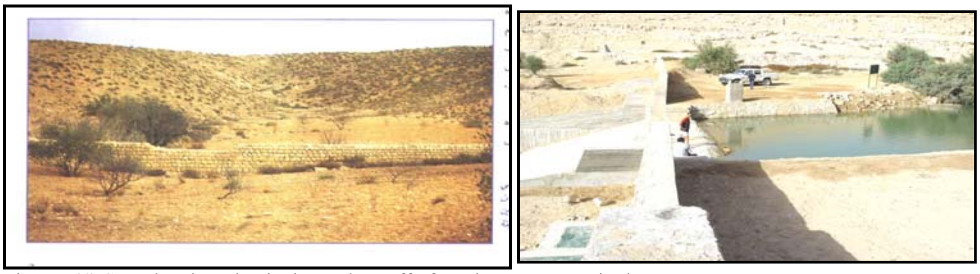


Figure (3) locations of the cisterns in the North-East part of Sinai.



Figures (4) Stored and productively used runoff of catchment system in the RWH.

Variability of annual rainfall

Water harvesting planning and management in arid and semi-arid zones present difficulties which are due less to the limited amount of rainfall than to the inherent degree of variability associated with it. Precipitation in the area of study results largely from convective cloud mechanisms producing storms typically of short duration, relatively high intensity and limited areal extent. However, low intensity frontal-type rains are also experienced, usually in the winter season. When most precipitation occurs during winter, relatively low-intensity rainfall may represent the greater part of annual rainfall.

For a water harvesting planner, the most difficult task is therefore to select the appropriate "design" rainfall according to which the ratio of catchment to cultivated area will be determined.

Design rainfall

Is defined as the total amount of rain during the cropping season at which or above which the catchment area will provide sufficient runoff to satisfy the crop water requirements. If the actual rainfall in the cropping season is below the design rainfall, there will be moisture stress in the plants; if the actual rainfall exceeds the design rainfall, there will be surplus runoff which may result in damage to the structures. The design rainfall is usually assigned to a certain probability of occurrence or exceedance. If, for example, the design rainfall with a 67 percent probability of exceedance is selected, this means that on average this value will be reached or exceeded in two years out of three and therefore the crop water requirements would also be met in two years out of three. The design rainfall is determined by means of a statistical probability analysis.

Rainfall Frequency analysis

The probability analysis is important to determine the probability or frequency of occurrence of yearly or seasonal rainfall for the cropping season from the area of concern. Due to the lack of the rainfall records in the area of study, figures from stations nearby were used. It was important to obtain long-term records because the variability of rainfall such arid and semi-arid areas are considerable. Figure (5) shows the Intensity Duration Frequency Curves for the area of east Sinai - Egypt.

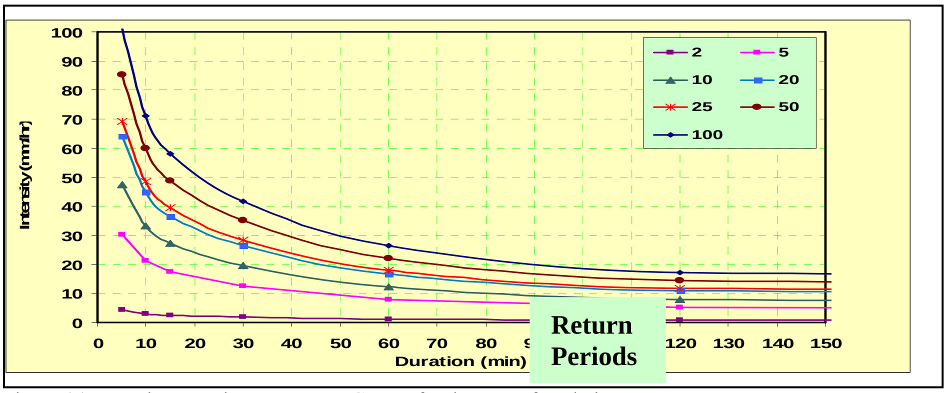


Figure (5) Intensity Duration Frequency Curves for the area of study in Egypt.

Groundwater Recharge

In places where the withdrawal of water is more than the rate of recharge an imbalance in the groundwater reserves is created. Recharging of aquifers is undertaken with the following objectives: Maintain or augment natural groundwater as an economic resource; Conserve excess surface water underground; and Combat progressive depletion of groundwater levels, and unfavorable salt balance and saline water intrusion.

1. Design of an aquifer recharges system:

To achieve these objectives it is imperative to plan out an artificial recharge scheme in a scientific manner. Thus it is imperative that proper scientific investigations be carried out for selection of site for artificial recharge of groundwater. The proper design includes the following considerations:

- ❖ **Selection of site:** Recharge structures should be planned out after conducting proper hydro-geological investigations. Based on the analysis of this data it should be possible to:
- ❖ Define the sub-surface geology.
- ❖ Determine the presence or absence of impermeable layers or lenses that canimpede Percolation
- ❖ Define depths to water table and groundwater flow directions
- ❖ Establish the maximum rate of recharge that could be achieved at the site.
- ❖ **Source of water used for recharge:** Basically the potential of rainwater harvesting and the quantity and quality of water available for recharging, have to be assessed.
- ❖ **Design of recharge structures and settlement tank:** For designing the optimum capacity of the tank, the following parameters need to be considered: (1) Size of the catchment, (2) Intensity of rainfall, (3) Rate of recharge, which depends on the geology of the catchment. The capacity of the tank should be enough to retain the runoff occurring from conditions of peak rainfall intensity. The rate of recharge in comparison to runoff is a critical factor.

However, since accurate recharge rates are not available without detailed geo-hydrological studies, the rates have to be assumed. The capacity of recharge tank is designed to retain runoff from at least 15 minutes rainfall of peak intensity.

2. Design of a recharge trench

The methodology of design of a recharge trench is similar to that for a settlement tank. The difference is that the water-holding capacity of a recharge trench is less than its gross volume because it is filled with porous material. A factor of loose density of the media (void ratio) has to be applied to the equation. In designing a recharge trench, the length of the trench is an important factor. Once the required capacity is calculated, length can be calculated by considering a fixed depth and width.

Appropriate techniques and Promising Areas in Sinai

Water harvesting for agriculture requires a more complex system than do the other systems. The size of the catchment area in relation to that of the agricultural area must be balanced against crop demands topography, provided there is a level area to farm and care is taken with catchment construction to provide low slopes, or, in steep terrain, short slope lenghts broken by diversions. Promotion of water harvesting should be done in conjunction with crops.

Individually based water Conservation/harvesting systems to a large extent have been more successful than collective based systems. Communally owned systems such as rain water harvesting and storage reservoirs were found to suffer from lack of protection, care and maintenance. Water harvesting initiatives and interventions need projects aimed at improving existing individual farmer practices on water harvesting as shown in Figure (6). There is no universally "best" system of water harvesting. However, there will be some type of system that can be designed to best fit within the constraints of a given location. Each site has unique characteristics that will influence the design of the most optimum system.

Figures (6): Example of the improved water harvesting system.

All factors, technical, social, physical and economic must be considered. During the past two decades, there have been many water harvesting systems constructed and evaluated at a number of different places in the world. Some of the systems have been outstanding successes, while others were complete failures. Some of the systems failed, despite extensive effort, because of poor design or the materials used. Other systems failed despite good design and proper materials because social factors were not integrated into the systems. These systems failed because of poor communication and lack of commitment by the local people both in planning and financing the projects. A successful system must be: Technically sound, properly designed and maintained; Economically feasible for the resources of the user; and Capable of being integrated into the social traditions and abilities of the users.

Much has been learned over the past two or three decades. Much more remains to be learned, but sufficient knowledge and experience have now accumulated to put into operation water harvesting projects throughout the arid lands of the world. Empirical information and documentation is needed from successes as well as failures on which to build a more exact technology.

Figure (7) shows the promising areas in Sinai for water harvesting. The runoff coefficient in most of Sinai Wadis is considered very low, for example in Wadi Al-Arish the runoff coefficient is about 0.01 which is considered very low and most of the rainfalls water volume is lost through percolation, seepage and evaporation. It was concluded that the largest average rainfall annual volume allover the basins is that of Al-Arish basin with an average value of 1.1 billion m^3. Therefore, El-Rawaafaa dam has been constructed in 1946 to protect Al-Arish city that locates on the Mediterranean shore in North-East Sinai. The dam has a storage capacity of 2.0 million m^3 with a length of 70 meters and height of 12 meters. In 1986, the dam crest was raised two meters high than the original crest and this increases the storage to be 6.8 million m^3. In 1989, a pump station and a pipeline were constructed to irrigate an area of about 170 Hectares downstream of the dam. The other basins in Sinai having an average annual values range from 10 to 129 million m^3. The Figure shows also the other dams in North and South Sinai. The development of Sinai will contribute significantly to the national economy due to the different variables and planning for the future.

Wadi Watair area at the south of Sinai is the most promising area because previous studies showed that a relatively large amount of flood water is lost every year to the Gulf of Aqaba while damaging roads and infrastructures. However, the problem will be the sustainability of using such stored water in detention dams due to the highly uncertainty in the hydrological cycles and rain fall intensity allover Sinai Peninsula.

The study revealed that Wadi Watier receives reasonable amounts of rainfall which can support some activities to enhance the sustainable development of the area. Protection and utilization structures are essential to prevent possible destruction due to floods and to ensure the maximum use of available runoff water. Eleven detention dams and five artificial lakes are proposed to develop the area and prevent possible disasters as shown in Figure (8). Locations of dams are selected according to peak discharges and total available volumes. Sites with narrow cross-section and large water volumes are selected to reduce the overall cost of the protection and storage system. Selected sites have both high peaks and large volumes of water.

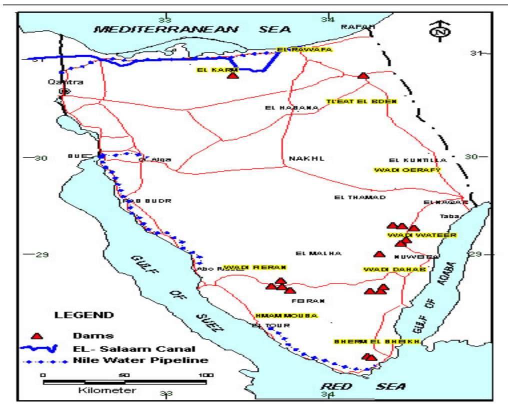


Figure (7): Location of promising areas and flash-floods control dams in Sinai

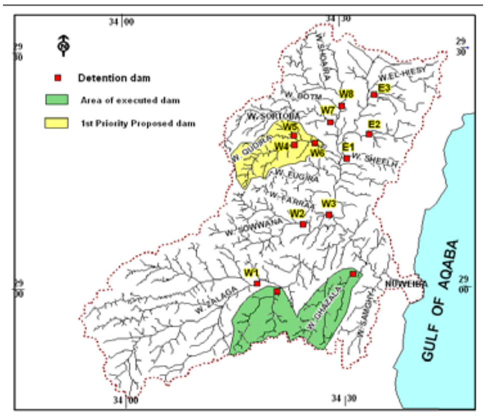


Figure (8) Executed and Proposed dam areas of Wadi Watier Development Project

Conclusions and Recommendations

Water harvesting offers a method of effectively developing the scarce water resources of arid regions. As contrasted to the development of groundwater, which is usually a finite water resource in arid zones, the method allows use of the renewable rainfall which occurs, even though in limited amounts, year in and year out.

Water harvesting can be undertaken through a variety of ways: Capturing runoff from local catchments; Capturing seasonal floodwaters from local streams; and Conserving water through watershed management.

Poor management and lack of maintenance are the main reasons for the failure of the RWH projects; therefore, directly concerned people should be included in all phases of the RWH projects: planning, development, implementation, operation and maintenance.

Building capacities (institutional and human resources) are essential to develop and implement the appreciate RWH programmes.

References

Moh. 1999. "Basic Studies for Flash Floods Protection", Ministry of Housing and New Communities, August 1992.

Mohamed A. Sonbol , F. Mtalo , and M. Abdel-Motteleb, 2005. "Watershed Modeling of Wade Sudr and Wade Al-Arabain in Sinai Egypt" International Conference of UNESCO, FLANDERS FIT FRIEND/NILE Project, Towards a better Cooperation, 12-15 Nov. 2005, Sharm El-Sheikh, Egypt.

Nasser, M. 1999. " Assessing desertification and water harvesting in the Middle East and North Africa: Policy implications", Center for Development Research, (ZEF), (10), 59.

Prinz,D. and Singh,A.K. 2000. “Water Resources in Arid Regions and Their Sustainable Managenet” Annals of Arid Lands, Special Issue on Research.

UNDP. 2003. “Sustainable Development in Egypt” Final Report. Cairo, Egypt

WRRI. 2002. "Integrated Rural Development Project for Northern Sinai Uplands-Ser 67", Water Resources Research Institute, National Water Research Center, Ministry of Water Resources and Irrigation, Egypt.

WRRI . 2003. "South Sinai Water Resources Development Project-Ser 92", Water Resources Research Institute, National Water Research Center, Ministry of Water Resources and Irrigation, Egypt.

الأنظمة المستدامة لحصاد مياه الأمطار والسيول بالمناطق القاحلة: شبه جزيرة سيناء– جمهورية مصر العربية

محمــد علــى ســنبل

معهد بحوث الموارد المائية – المركز القومي لبحوث المياه – القناطر الخيرية – مصر

مما لاشك فيه أن الماء من أهم مقومات الحياة لجميع الكائنات الحية، ولايمكن لأى تنمية بشرية أو زراعيــة أن تقوم وتزدهر إلا بتوافر مايلزمها من المياه. ولذلك فإنه في الآونة الأخيرة قد حظيت المياه بالاهتمام الجاد مــن حيــث الإدارة السليمة أو عدم الاستخدام المفرط حتى لا يحدث التلوث وتدهور لنوعيتها. ومن المعروف أن المنــاطق القاحلــة بمصر مثل سيناء تعانى من العجز الكبير في مواردها المائية التي تتطلبها برامج التنمية التي تواكب الزيادة المطردة في عــدد السكان، والتي تتناسب مع التطور التنموي ومستلزمات العصر الحديث.

وفي هذا البحث فقد تم البحث عن الوسائل العلمية والتكنولوجية للحصول على مصادر المياه الغــير تقليديــة بسيناء مثل طرق استخدام حصاد مياه الأمطار والسيول الموسمية، تخزين مياه السيول الموسمية بالخزانات التحت ســطحية (هرابات) والخزانات السطحية المختلفة. وبناءا على نتائج هذا البحث، فقد تم تحديد أحواض التصريف المختلفة بــسيناء وحساب الموارد المائية السطحية، ودراسة معدلات الأمطار والسيول الناتجة عنها. وعلى ذلك فقد تم وضع إســتراتيجية عامة بسيناء لتحقيق التنمية المستدامة من خلال الاستخدام الأمثل للموارد المائية التقليدية والغير تقليدية. وكذلك، فقــد تم تحديد أفضل الطرق لاستخدام الموارد المائية وحصاد السيول في الإنتاج الزراعي. ومن نتائج دراسة إمكانيات الأمطار والسيول الموسمية فقد تم تحديد المساحات الزراعية الواعدة، وكذلك وضع التصور والتصميم الإنشائي لبعض مشروعات حصاد مياه الأمطار مثل السدود الصغيرة وسدود الإعاقة حيث يمكن استخدام هذه المياه للأغراض المترليــة، الــشرب، الزراعة، او في تغذية الخزان الجوفي الضحل. وقد أوصى هذا البحث أيضا على سبل تنمية العيــون الطبيعيــة بــشمال وجنوب سيناء، عمل المتابعة والصيانة المستمرة للخزانات السطحية ومنشآت حــصاد الأمطــار، والإدارة المتكاملــة للموارد المائية.

الكلمات المفتاحية: وادى ، المناطق القاحلة ، إدارة الموارد المائية ، التنمية المستدامة ، سدود الإعاقة.