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Water Harvesting and Flashflood Mitigation-Wadi Watier Case Study (South Sinai, Egypt)

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Abstract: Egypt's Sinai Peninsula is suffering from water shortages. Although Sinai has limited rainfall, flashfloods are responsible for huge losses of lives and infrastructure. The objective is to evaluate the water harvesting potential in, the semi-arid, water scarce and flashflood prone, 3600 km^2 Wadi Watier, South Sinai, Egypt. The analysis is based on the Integrated Water Resources Management (IWRM) guidelines. Therefore, physical, social, environmental andinstitutional analyses were carried out. The potential runoff was estimated by applying the Soil Conservation Services (SCS) method using the Hydrologic Engineering Center (HEC-1) model. Additionally, interviews were done with local residents (Bedouins) to reflect water harvesting social acceptance, water consumption andwater uses. Besides, Institutional and Environmental analysis were reviewed from literature. Later, ArcGIS software was used to examine the potential sites by combining different geology, slope and land users layers. The results showed a promising potential for water harvesting with the area. Estimated 0.24, 0.45 and 2.7 million m^3 could be harvested respectively for 2-,3-and 25-year return periods. Moreover, water harvesting techniques are socially accepted by Bedouins (91% of the interview sample) but not in funding these techniques. Also, 85% of the respondents prefer to use the harvested water for drinking, while 45 % of them favour it for grazing as a second choice. Consequently, wadi-bed and off-wadi water harvesting systems have been proposed with 6 techniques, such as Cisterns and Jessour. In conclusion, water harvesting could also provide one more conventional water resource andsimultaneously, mitigate flashflood hazards downstream by impounding water in specific locations upstream.

Key words: Water harvesting · IWRM · Flashflood mitigation · WMS · Bedouin · Egypt

INTRODUCTION

Sinai Peninsula is located at a unique position, both geographically and politically andis blessed with many natural resources. Hence the area chosen to play a vital role in the Egyptian master plans to create new settlements [1]. Fresh water availability is essential for any effort to establish new societies. Therefore, the Egyptian government implemented El-Salaam canal to transfer the Nile water to Sinai. However, it is not possible to transport Nile water to all over Sinai due to particularly high cost [2]. Southern Sinai is far from the canal with limited water resources. Therefore, a rational management of the current water resources, e.g. rainfall, is crucial. Rainfall is limited in the area; however, flashfloods occur causing losses of lives and infrastructure [3]. Good management can turn flashflood from a hazard into a valuable water resource.

Wadi Watier is one of the most active wadis in Sinai. The Wadi is located in the southeastern part of Sinai (Figure 1). It has an area about 3,500 km^2 with 70 km main stream length. The outlet of the wadi is Nuweiba city. It is a tourist hub and has an international harbor.

No different from the whole Southern Sinai, water resources are very limited in Wadi Watier, which consist of groundwater and desalinated sea water. Bedouins, local residences in Watier, do not have sufficient water to meet their needs [4]. They suffer from agriculture

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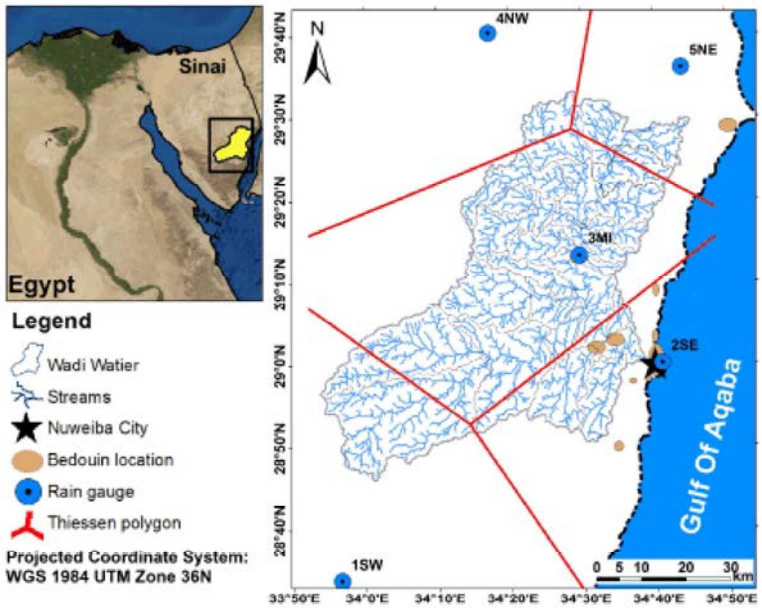


Fig. 1: Location of Wadi Watier and Metrological stations.

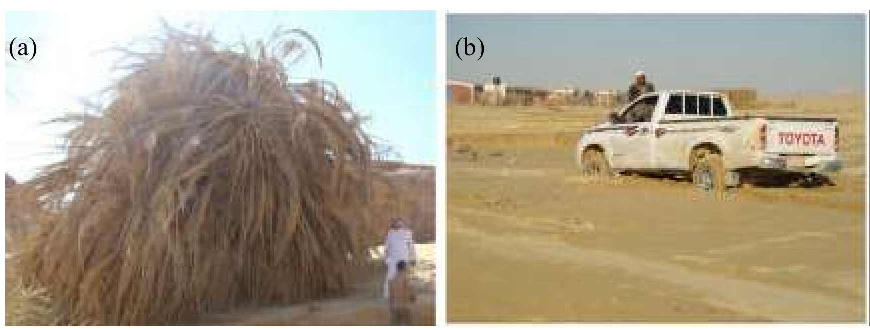


Fig. 2 : Agriculture damage (a) and Local Bedouin after last flashflood event in 2010 (b)

damage and cattle death (Figure 2). Besides, pressure on the available water resources is high and will increase due to population growth. In 2011, the population is estimated to be 21,000 inhabitants. Population may double to 47,000 inhabitants in 2017 [4]. On the other hand, the area is at risk from flashflood (Figure 2). In 1990, 1997, 2002 and 2010, the area was subjected to flashfloods hazard, most of them were severe and left huge losses of lives and infrastructure. In addition, Nuweiba City becomes flooded due to its geographical location by the flashflood. Disasters have been reported at the Nuweiba-Dahab Highway [3].

Water harvesting is defined as the collection of runoff for beneficial use [5]. It can provide additional water resources. This would increase the total amount of available water which could support the Bedouins' needs. In addition, water harvesting structures reduce the water velocity during flashflood events by increasing the concentration time of the hydrographic basins and reducing the flood peak [6]. A developed flood analysis model predicted that water harvesting structures can reduce flood peak-flows and volumes by up to 70% in Petra catchment, Jordan [7]. In conclusion, water harvesting is seen as a suitable solution in Wadi Watier. The availability of surface water as flashflood can be used as a potential water resources rather than disaster phenomena. The aimed target can be fulfilled through the following main objectives of the research:

- Estimating the potential amount of water that could be harvested.
- Identifying potential sites and techniques for water harvesting throughout the catchment.

MATERIAL AND METHODS

Overview: Selection of water harvesting sites and techniques was based on integrated water resources management (IWRM) guidelines to obtain a sustainable development for any implemented project [8].

Therefore, physical, social, environment and institution analyses were carried out. The considerations in sighting were dependent on the analysis of the volume of water, the topography andthe geology characteristics beside the collected socioeconomic data. These factors are combined to select the suitable site and technique for each sub-watershed. Physical factors such as water volume estimation and land/soil type analysis were carried out.

Water Volume Estimation: Rainfall analysis was done using data from five rainfall stations (Figure 1) with daily records from 1989 to 2005. The data sources were Egyptian General meteorological Authority (GMA) and Water Resources Research Institute (WRRI). Thiessen polygon [9] was used to define each rain gage affected area. Nevertheless, understanding of the hydrological process was needed to ensure proper use. The selected computer Rainfall-Runoff model was Hydrologic Engineering Center (HEC-1) [10] under Watershed Modeling system (WMS) software [11] as it was successfully applied for water harvesting and flashflood mitigation studies in arid and semi-arid areas [7, 12-13]. Wadi Watier was divided into 25 sub-watersheds using the WMS powerful automated basin delineation tool (Figure 1) coded as (1 to 25B). As well, HEC-1 was used to simulate the surface runoff from precipitation. Wadi Watier is an ungauged catchment. Regarding [14], Soil Conservation Service (SCS) rainfall–runoff models are recommended for ungauged catchment. Accordingly, the SCS unit hydrograph method was used to convert the rainfall data to synthetic runoff. The only available data for infiltration was geological map. Therefore, SCS hydrologic infiltration rate method was used [9]. Curve Number (CN) values for Alluvial, Limestone and Volcanic rocks classes were adopted from [15] while rest of CN was estimated form geological description from [16]. After rainfall data analysis, catchment delineation and CN estimations, 179 runs were done which presented the historical rainy days. The daily synthetic water volume outputs were converted to seasonal synthetic water volume for each sub-watershed. To determine frequency flood occurrence, DISTRIB application in Stormwater Management and Design Aid (SMADA) software [17] analyzed the seasonal synthetic runoff return period. This was done for each sub-watershed and for the whole wadi. Statistical models such as Log Person type III and Two parameters Log Normal model were used to get the best fit for the results.

Topographic Terrain and Soil Analysis: The ground slope is a key limiting factor in water harvesting [5]. The slope of the study area was derived from a 30 m digital elevation model (DEM) [18] using Spatial Analyst tool in ArcGIS. Furthermore, soil type is important to investigate the behavior of captured water either for direct use or for groundwater recharge [19]. Therefore, the geological map was classified to the main rock formation then permeability estimation was given for each geological class.

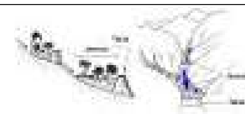
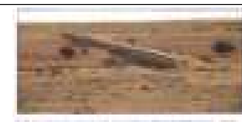
Interviews: Socioeconomic status is very important in order to help the decision makers when planning any scheme for a sustainable development [8]. A field survey was conducted to investigate the social attitude towards water harvesting application and to find out the following parameters through personal interviews with a questionnaire form: water use, existing application andtheir opinion about water harvesting. 94 questionnaire forms were collected from eight different locations in Wadi Watier.

Environmental and Institutional Analysis: Harvesting water by building big dams will have a bad impact on the ecological sustainability especially within arid areas. It was concluded from Environmental Impact Assessment (EIA) report [20] for the flood protection works of Wadi Dahab which is close to Wadi Watier and the outlet of the wadi is also located at the Gulf of Aqaba. Accordingly, building big dams was not recommended in Wadi Watier.

Finally, the institutional investigation was carried out to distinguish the current policy and strategy regarding water harvesting in Sinai and particularly in Wadi Watier. Floodwater control and harvesting are seen as one of the actions needed to develop the local-municipal services in South Sinai Environmental Action Plan (SSEAP) [4] xsxxxxxx. Furthermore, flashflood water harvesting in Sinai is adopted at the Egyptian water policy [1]. In conclusion, there is no obstacle with regard to study and implement flashflood water harvesting in Sinai.

Water Harvesting Suggested Technique: Floodwater harvesting was adopted in this study. It has two types: Stream and diversion floodwater harvesting. Stream Floodwater harvesting is achieved by constructing a small structure across the wadi while Floodwater diversion is defined by forcing water leaving its natural course [5]. Some of the water harvesting techniques (Table 1) was seen suitable for Wadi Watier which was selected from previous studies [5, 6, 19, 21].

Table 1: Selected traditional water harvesting techniques suggested for possible implementation

System	Purpose	Permeability	Slope	Illustrated photo	Source
Stream Floodwater harvesting					
Jessour	Agriculture	Impervious and Semi-pervious	>12%		[19]
Wadi-Bed cultivation	Any	Pervious to Semi-pervious	4-12%		[21]
Check Dam	Any	Impervious	<12%	-	[5, 6]
Floodwater diversion					
Percolation ponds	Groundwater recharge	Pervious	<10%		[5]
Tanks and Hafair	Any, except Groundwater Recharge	Impervious and Semi-pervious	<9%	-	[5,19]
Cisterns	Domestic and Agriculture	Impervious	Any	-	[5, 19]

Sighting and Selecting Criteria: ArcGIS software was used to examine the potential sites by combining different topography, land slope, permeability and land users layers for each sub-watershed. Besides, the technique was chosen based on the social analysis, if found, then physical analysis (potential water volume, geology, slope andsoil) for each sub-watershed.

RESULTS AND DISCUSSION

Water Volume Potentiality: According to the established criteria, Figure 3 shows the synthetic max storm per season and total seasonal synthetic water volumes for Wadi Watier for period (1989 to 2005).

As shown in Figure 3, five flashflood events were simulated in (1989/1990, 1990/1991, 1993/1994, 1994/1995 and 2002/2003) seasons. According to [3], Historic flashflood events in Wadi Watier for these years were reported. Flashflood with moderate event happened in 1990/1991 and 2002/2003 while no reporting in 1994/1995. Although a high flashflood was reported in 1997/1998 [3], the model presents a low runoff value. The reason could be missing data for some stations due to defect in the gauge during the rain event. However, the model's output was used to predict water volume which could be harvested (Table 2) from the return periods.

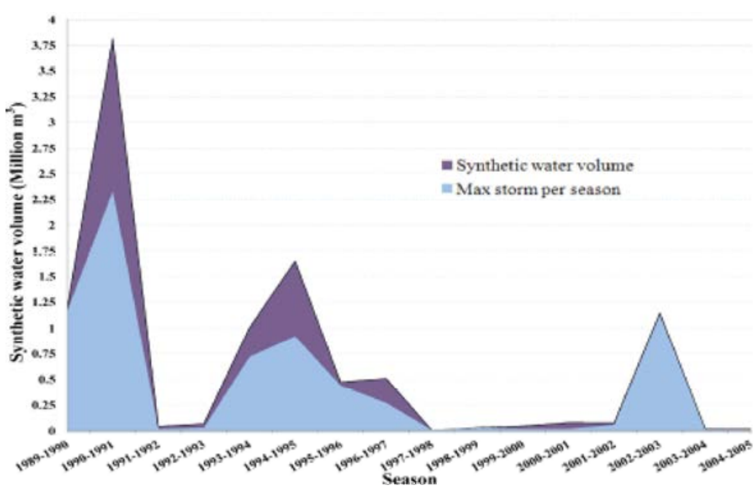


Fig. 3: Synthetic maximum storm per season and total seasonal water volumes for Wadi Watier.

Table 2: Return period for the total synthetic water volume for Wadi Watier

Probability	Return Period (Years)	Water Volume (Million m^3)
0.5	200	11
0.667	100	6.8
0.8	50	4.3
0.9	25	2.7
0.96	10	1.4
0.98	5	0.77
0.99	3	0.45
0.995	2	0.24

Table 2 shows low water volume return period values. The analysis was based on the actual rainfall events. No single storm covered the five stations. Only a greatest storm noticed from the historical data were recorded at four rainfall stations. In addition, some of the sub-watersheds have zero output in the seasonal synthetic runoff, which reflect the low presented value. However, the current simulation model presents the minimum water volume produced within Wadi Watier. Designing water harvesting system should base on lower values not even on the average values to ensure greater dependability of the system [21]. In conclusion, the current model's result could be used for water harvesting study as it could present the minimum water volume potentiality in the study area. The low return periods (2 and 3 years) were selected for domestic and agriculture purposes to assure water availability within small time periods while up to 25 years return period was used for other purposes as groundwater recharge.

Topographic Terrain and Soil Analysis: The slope map is used to identify suitable water harvesting locations. The minimum slope was 0% and the maximum value was 235.59 % (67 degrees). The average slope was found to be 17%. However, it is distinguished that the wadi upstream has the minimum slope values while the slope has the highest values at the downstream especially at the main stream close to the outlet of the wadi. The soil permeability map showed that a small part, 20%, of watershed is pervious. The impervious and semi-impervious formation rocks are equally covered. The impervious formation presents 39% and covers vast area at the upstream at the watershed outlet.

Interviews: Due to the fact that the water shortage in the region, Bedouins have since decades practiced water harvesting. 26% of the sample has simple and primitive water harvesting techniques. Also, from the interviews it was found that majority of the respondents (91%) agreed on the implementation of water harvesting. The survey also showed that 60% prefer to use the harvested water for drinking. Bedouins are not interested in investing time and/or money for applying water harvesting project. Around, 60% of the sample refused to do efforts in implementing water harvesting project. Bedouins see that building water harvesting techniques to support them with water is the responsibility of the government (around 49% of the comments indicate that). However, the 40% of the sample are wishing to share time and efforts only when a big project will be implemented. Also, they confirmed that they cannot share any money as the financialsituation is not secured. In conclusion, respondents agree for implemented water harvesting techniques but not in funding these techniques.

Water Consumption: Typical water use such as domestic, grazing (meat and milk production), irrigation, or industrial leads to water consumption. From the questionnaire, 85% of the respondents prefer to use the harvested water for domestic use mainly for drinking (46%), while 45 % of them favour it for grazing as a second choice. The agriculture came to the third choice with 36% while the industrial activity such as leather production has the lowest percentage (7%). It can be concluded that the main purpose of the water harvesting will be for the drinking and domestic use.

World Health Organization (WHO) adopted 20 liter/capita/day as minimum requirement water volume for domestic use for public stand pipe closer than 1km in rural area. However, the rural household water use for dry climate is ranged between 30 to 40 liter/capita/day [22]. Thus, the adopted water requirement for domestic use for Wadi Watier is 40 liter/capita/day. The maximum number is selected as some Bedouins could use the harvested water for other activities. Consequently the seasonal required water is 14m^3/ person/year. Due to the lack of the total number of Bedouins information, the identification of suitable technique was based on the potential harvested water for that purpose.

Water Harvesting Potential Sites and Suggested Systems: Matrix Decision Support System (MDSS) is created to identity the water harvesting location and techniques for the 25 sub-watersheds in Wadi Watier (Table 3). The decision factors are identified from social and physical analyzed data.

Table 3: Matrix Decision Support System for sitting and selecting water harvesting techniques

		Social			Physical				
Wadi Code	Water Volume	Village Name	Water demand	Req. System	Permeability	Soil Agriculture	Terrain Slope%	Proposed Techniques	Purpose
1B	5	-	-	-	P/S layer	Valid	10	1,4	GW
9B		-	-	-	S/I layer	Valid	13	1,4	GW
2B	12	-	-	-	P layer	Valid	6	1,4	GW,GZ
3B		-	-	-	S layer	Not valid	10	1,4	GW,GZ
5B		-	-	-	P layer	Valid	13	1,4	GW,GZ
13B	5	El Shikh Atia	A/D	Dam/Water tanks	I layer	Not valid	17	1,5	GW,GZ,DM
14B	1	El Shikh Atia	A/D	Dam/Water tanks	I layer	Not valid	21	5	DM
15B	16	-	-	-	P/S/I layer	Valid	19	1,4	Any
16B	16	-	-	-	S/I layer	Not valid	20	4	GW
17B		-	-	-	P layer	Not valid	18	1,3	GW,GZ
18B	16	Ain Om Ahmed	A/D/G	RC dam	S/I layer	Not valid	28	1,3	GW
19B		Ain Om Ahmed	A/D/G	RC dam	P/S layer	Valid	18	1,4,5	Any
20B		-	-	-	P/S layer	Valid	17	1	Any
21B		-	-	-	S/I layer	Not valid	16	4	GW
24B	5	-	-	-	I layer	Not valid	21	2,3	Mitigation/GZ

Legend:

Water Demand: A: Agriculture, D: Domestic use, G: Grazing

Permeability: P: Pervious, S: Semi-pervious, I: Impervious

Proposed Techniques. 1: Check Dam, 2: Wadi-Bad cultivation, 3: Jessour, 4: Percolation ponds, 5: Cistems

Purpose: GW: Grroundwater Recharge, GZ: Grazing and Agriculturs, DM: Dom estic Use

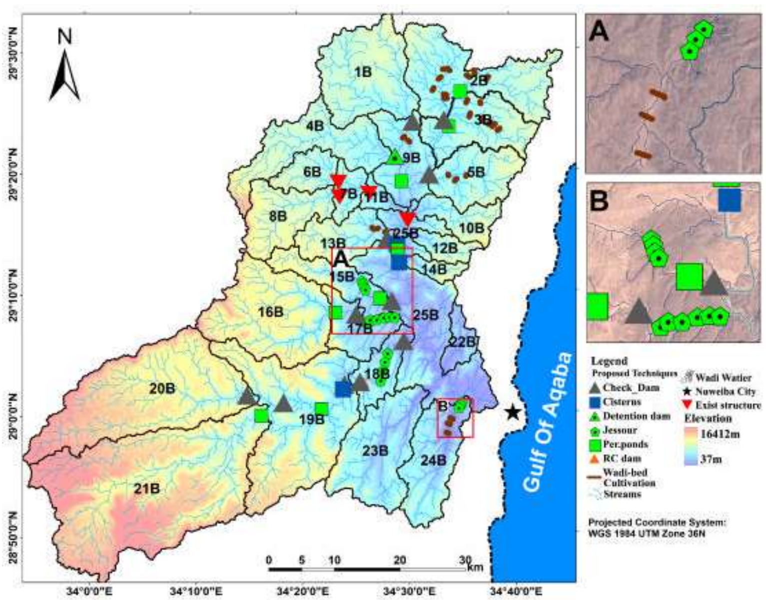


Fig. 4: Proposed water harvesting techniques for Wadi Watier

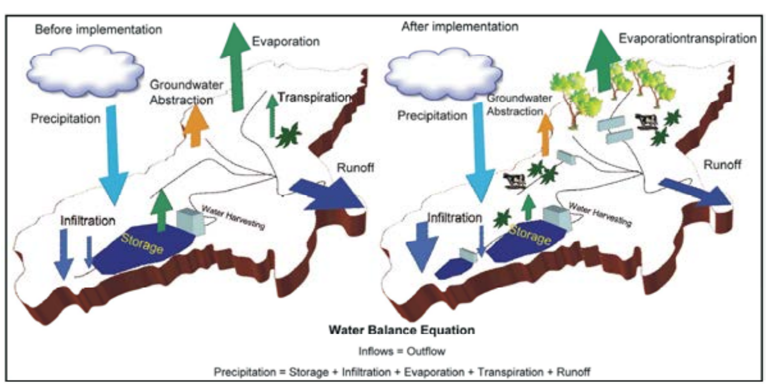


Fig. 5: Possible flashflood mitigation as a result of applying water harvesting.

Figure 4 shows the suitable locations for direct usage in form of surface water storage, indirect usage in form of groundwater recharge, and/or both usages. No technique is proposed for the most of the eastern sub-watersheds of Wadi Watier, as these sub-watersheds have small areas and low produced runoff. Besides, no official Bedouins communities are reported or found in these sub-watersheds during the field visit.

Water Harvesting and Flashflood Mitigation: From water balance concept (Figure 5), once water is kept in a watershed (storage and infiltration), this might reduce the amount of the produced runoff [6, 7]. As well, increasing the storage capacity in the surface layer reduce flashflood occurrence. Consequently, the proposed strategy for applying water harvesting structures may inhibit the destructive flashfloods by reducing the water velocity during flashflood events and flood peak.

CONCLUSIONS

Floodwater harvesting potentiality of Wadi Watier was assessed based on IWRM guideline with physical, socioeconomic, environmental andinstitutional data analysis. The potential runoff was estimated by applying the Soil Conservation Services (SCS) method using the Hydrologic Engineering Center (HEC-1) model. The result could not be calibrated against observed discharge due to the absence of discharge measurement stations. Potential water volume return period was calculated for each sub-watershed. The results show a promising potential for water harvesting within the area. It is estimated that 0.24, 0.45 and 2.7 million m3 could be harvested for 2-, 3-and 25-year return periods, respectively. In addition, interviews were carried out with Bedouins in order to reflect the social acceptance, water consumption and the different water uses. Later, ArcGIS software was used to examine the potential sites by combining different layers. The water harvesting scheme location and technique selection was based on the social data then the physical analysis (geology, slope, soil). The suggested floodwater harvesting type for the watershed could include check dams, Wadi-bed cultivation, Jessour, percolation ponds andCisterns. As an expected result, water harvesting could also provide one more conventional water resource and simultaneously, mitigate flashflood hazards downstream by impounding water in specific locations upstream.

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