ALGORITHM TO LOCATE POTENTIAL WATER HARVESTING SITES IN NON-URBAN AREAS

UN ALGORITHME POUR LOCALISER LES SITES POTENTIELS DE COLLECTE D'EAU DANS LES ZONES NON-URBAINES

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ABSTRACT

Fresh water is the most important substance in arid and semi-arid areas. Variability in space and time is an inherent characteristic of precipitation in these regions. In this regard, the proper use of this scarce source of fresh water is of vital importance and needs more attention. Water harvesting is one of the most appropriate ways to supply fresh water in arid/semi-arid regions.

I this research, in a study area in the Southeastern part of Iran, an algorithm was developed to identify the potential locations for water harvesting sites. The algorithm uses geological, soil, topographical and precipitation map in the GIS environment. It addresses: 1- Water conservation potential in upstream, 2- Water harvesting potential in hilly areas, 3- Water harvesting potential in watercourses, and 4- Artificial recharge potential in the plains.

At the upstream, there are 3 options: Pitting, Contour Furrow and Bankt. All of these measures increase the infiltration capacity of the soil. In hilly areas, steep slope, imperviousness, and adequate rainfall are amongst the most important features for water harvesting. In this regard, stony areas, regions with a slope steeper than 20% and area with annual precipitation of 200 mm or more were selected. In water courses, to derive the appropriate reaches for water harvesting, the following criteria were combined: 1- The channels of rank 1 to 3 (the Strahler classification) 2- The reaches with a slope of 20% or more 3- The zones that receive annual rainfall of 150 mm or more. Finally for artificial recharge, by engaging different data layers such as terrain slope, surface infiltration capacity, transmisivity, ground water level, and water quality the extent of the proper water harvesting zone was identified.

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Using all of these options, about 25% of the study area was identified as suitable for water harvesting.

Key Words: *Rain Water Harvesting potential, Upstream, Hill slopes, Natural water courses.*

RESUME

L'eau douce est la substance la plus importante dans les zones arides et semi-arides. La variabilité dans l'espace et dans le temps est une caractéristique inhérente des précipitations dans ces régions. À cet égard, la bonne utilisation de cette source rare d'eau douce est d'une importance vitale et celle qui nécessite plus d'attention. La récupération de l'eau est l'une des façons les plus appropriées pour l'approvisionnement en eau douce dans les régions arides / semi-arides.

Dans cette recherche, dans une zone d'étude dans la partie sud de l'Iran, un algorithme a été développé pour identifier les emplacements potentiels pour des sites de récolte de l'eau. L'algorithme utilise la carte géologique, les sols, la topographie et les précipitations dans l'environnement GIS . Il aborde: 1) - le potentiel d'économie d'eau en amont, 2) - le potentiel de récolte d'eau dans les régions montagneuses, 3) - le potentiel de récolte de l'eau dans les cours d'eau, et 4) – le potentiel de recharge artificielle dans les plaines.

A l'amont, il y a 3 options: la formation des fosses, le sillon contour et Bankt . Toutes ces mesures augmentent la capacité d'infiltration du sol. Dans les régions montagneuses, une pente raide, l'étanchéité, et des pluies suffisantes sont parmi les caractéristiques les plus importantes pour la récolte de l'eau. À cet égard, les zones caillouteuses, les régions ayant une pente supérieure à 20% et la zone des précipitations annuelles de 200 mm ou plus ont été sélectionnés. Dans les cours d'eau, pour dériver les cours appropriés pour la récolte de l'eau, les critères suivants ont été combinés: 1) - Les canaux de rang 1 à 3 (la classification de Strahler) ; 2) - La atteint avec une pente de 20% ou plus ; 3) - Les zones qui reçoivent des précipitations annuelles de 150 mm ou plus. Enfin pour la recharge artificielle, en engageant différentes couches de données telles que la pente du terrain, la capacité d'infiltration de surface, transmissivité, le niveau des eaux souterraines et la qualité des eaux, l'étendue de la zone de récolte adéquate de l'eau a été identifiée.

En utilisant toutes ces options, environ 25% de la zone d'étude a été identifié étant adéquat pour la récolte de l'eau.

Mots clés: *Potentiel de collecte d'eau de pluie, en amont, pentes des collines, cours d'eau naturels.*

1. INTRODUCTION

There are several dry regions in Iran where fresh water is limited, rainfall is low and uncertain, agriculture is constrained and the regions are undeveloped. In some years, even the limited rainfall cause flood due to its erratic occurrence over space and time. This paper discusses the application Rain Water Harvesting (RWH) technique in a dry region of Iran. An algorithm was developed to derive suitable regions for RWH based on available data that could be handled in the GIS environment.

At the World Summit for Sustainable Development (WSSD) in 2002, water and sanitation were recognized as inextricably linked to the eradication of poverty and to the achievement of sustainable development. The UN General Assembly in late 2003 adopted a resolution that proclaimed the period 2005-2015 as the International Decade for Action-Water for Life (UNEP, 2005). More than two billion people will live under conditions of high water stress by the year 2050 suggesting that water could be a limiting factor for development in several regions of the world (Sekar and Randhir, 2007). Inadequate and extreme fluctuations in the amount of water available is a major constraint to productivity and profitability of agriculture, making most poor farmers remain at subsistence level and in perpetual poverty (Hatibu et al., 2006). Climate change and global warming make the water management issue more critical in some parts of the world. Climate change will increase crop water requirements, competition between weed and crops, salinization of soils, and the spreading extent of pests and nematodes (FAO, 2005). The combination of increased temperature and decreased rainfall would result in reducing yield of agricultural crops in arid regions (Al-Bakri et al., 2010).

The idea of using the RWH for water supply is not new. Water harvesting is believed to have been developed in ancient Iraq, 4000 to 6000 years ago, for supplying water to trade caravans (Shalaan, S.N., 2004). Water harvesting is an ancient art practiced in the past in many parts of North America, Middle East, North Africa, China, and India (Oweis et al., 1999; Sekar and Randhir, 2007).

Water harvesting has multiple benefits, which is revealed in several studies. For example in arid and semi arid regions water conveyance may entail a considerable amount of losses, while in the RWH harvested water is used at the project site (Lane, 1982). Li and Gong (2002) reported the successful application of rainwater harvesting to solve water problem for agricultural and domestic uses in semiarid regions of China. Water supplies traditionally rely on a single source, thereby impacting negatively on its reliability. Diversification of water sources, with one being domestic RWH (DRWH), offers greater prospects of reliability and good hygiene (Kahinda et al., 2010). In areas with dispersed populations and where the costs of developing surface or groundwater resources are high, rainwater harvesting and storage have proved a more affordable and sustainable intervention (UNEP, 2005). Rain water remains relatively inexpensive in many dry regions of Asia, Africa, and America and often is the only available source of water for agriculture (Bruins et al., 1986).

Remote sensing technology and Geographical Information System (GIS) have greatly helped RWH studies. Many recent studies have developed algorithms to identify the best locations for water harvesting among different alternatives. GIS has been recommended as a decision making and problem solving tool in rain water harvesting studies (Mbilinyi et al., 2005). There are a few investigations on finding the best location for siting reservoirs in RWH projects via web based GIS (Jabar and El-Awar, 2004; Mohter et al., 2006; Sekar and Landhir, 2007).

Flood spreading is the only type of the RWH that has been widely known in Iran. The RWH, as a watershed research program focused on flood spreading, started in Iran in 1969. The first project was implemented in Zanjanrood watershed in the Northwestern part of in 1972 and the second project was executed in Nodahak station in Qazvin province.

This research tries to show the capabilities of the other types of the RWH that can be used efficiently in arid and semi arid regions of Iran. Four different types of RWH are considered in the present research. They are: 1- Water conservation in upstream, 2- Water harvesting in hilly areas, 3- Water harvesting in watercourses, and 4- Artificial recharge (flood spreading) in plains.

The decision about the suitability of areas selected as potential areas for RWH depends on many factors, such as finances, cultural, political and local preferences that go beyond the scope of this research. Therefore, the results of the present research are limited to illustrating the potential areas for any types of RWH. It is worthwhile to mention that the developed algorithm is capable of addressing the time variation of the RWH with respect to the climate change via introducing the changes in land use, precipitation and temperature.

2. MATERIALS AND METHODS

2.1 Case study

The case study area is the Rabch-Bahookalat watershed in the South Balouchestan in the south - southeast of Iran. It is bordered by the Oman see in the south; the central deserts (Kavir Markazi) of Iran in the North; and Pakistan in the East. This 49000 km^2 watershed extends from 58^o 47’ to 63^o 12’ E longitude and from 25^o 3’ to 27^o 2’ N laltitude. The important rivers are the Rabch, Kahir, Sarbaz, and Bahookalat. More than 60% of the watershed is in plains. The annual precipitation varies between 300 mm and 100, the annual temperature ranges from 18 to 28 ^{o}C. This region is in the subtropical zone, and precipitation may occur in all seasons due to the influence of Monsoon from the South and the pluvial fronts from the West. Because of the low annual precipitation and its uneven spatial/temporal pattern, the climate is arid and ultra arid with a poor land cover. Figure 1 illustrates the location and climatological conditions, and Figure 2 shows the plains and rivers of the study area.

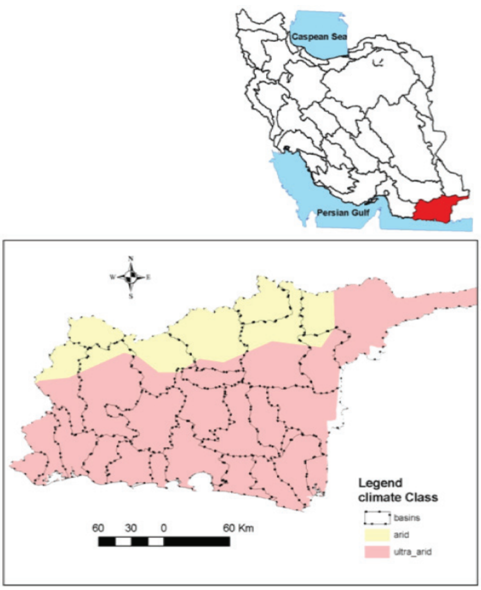

Fig. 1. Location and climatological conditions of the study region

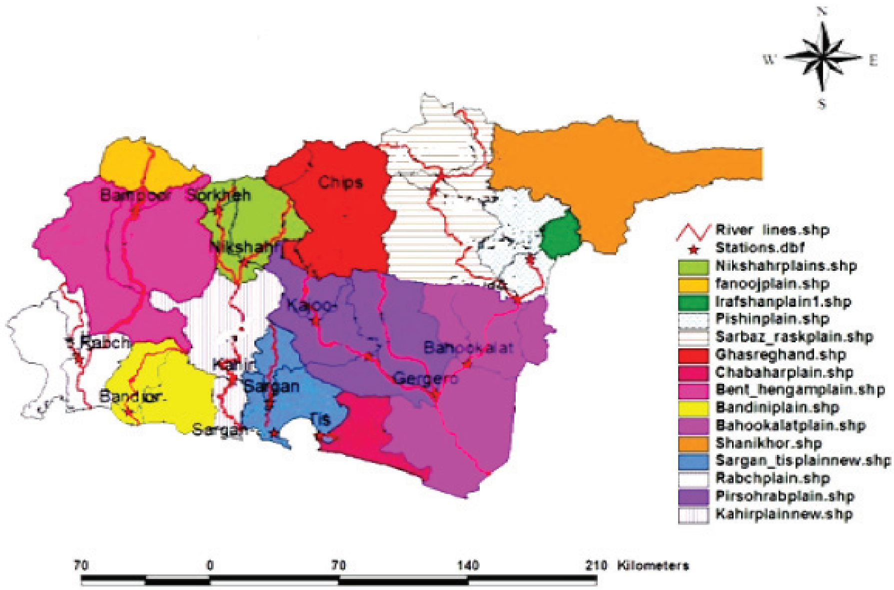

Fig. 2. Plains and rivers of the study area

2.2 RWH methods

There are different methods for rain water harvesting used for different purposes like soil conservation, saving soil moisture, and satisfying agricultural and potable water demands. In the following sections the developed algorithm for the aforementioned types of RWH and the results of its application in the study area will be discussed.

In situ RWH. This type of RWH is for conservation of soil and water in the upstream parts of watersheds. Runoff at the upstream sections of watersheds erodes soils, especially in the absence of a good land cover and steep slope. Saving rainfall in situ will reduce the runoff and its adverse impact, while the infiltrated water could be accessed as subsurface runoff and underground water across the watershed. The conserved water can rejuvenate the land cover, which in turn will increase the harvested water and reduce the floods. The study area in the South Balouchestan has experienced over-grazing during past decades that seems to be the most important causes of the recent severe floods in this region. Hence, in situ rain water harvesting can be a valuable remedy for this watershed. Investigation in the study area leads to the following methods for in situ RWH: Pitting, Contour Furrow, and Bankt.

Pitting: It refers to the digging of a V-shape hole into the ground for retaining rainwater to infiltrate and increase soil moisture content (Mesdaghi, 1999).

Contour Furrow: It is a furrow constructed on barren and steep rangelands to increase infiltration and control soil erosion (Mesdaghi, 1999).

Bankt: It is a canal constructed on steep hillsides and is one of the most common ways of soil and water conservation in arid and semi arid regions.

The in situ RWH, comprising the above three methods, is suitable for rangelands with poor to average condition. The following criteria were used to find the potential locations of in situ RWH:

a) Annual precipitation: 100-300 mm

b) Soil texture: medium to heavy

c) Overland slope: Pitting (<8%); Contour furrow (8-12%); Bankt (12-70%)

The criteria for the in situ RWH, regardless of the applied method, are the amount of rainfall and land use (non-agricultural) lands (FAO, 2001; FAO, 2003). Based on these criteria, the necessary maps were prepared and overlaid. The results are illustrated in Table 1 and Figure 3.

Table 1. Cumulative area (km^2) of the in situ RWH potential in the study area

Plain	Contour Furrow	Pitting	Bankt
Irafshan	126.4	38.5	302.5
Bahookalat	19.4	5	24.4
Benet	4.1	-	-
Pirsohrab	208.2	-	-
Pishin	158.8	4.6	193.9
Rask&Sarbaz	326.2	42.9	125.1
Sergan&Tis	5.8	-	-
Fanooj	1.1	0.1	0.6
Ghasre Ghand	494.4	180.3	75.3
Lash&Zarabad	13.2	-	-
Nikshahr	1.1	0	0.6
Total	1358.8	271.5	742.3

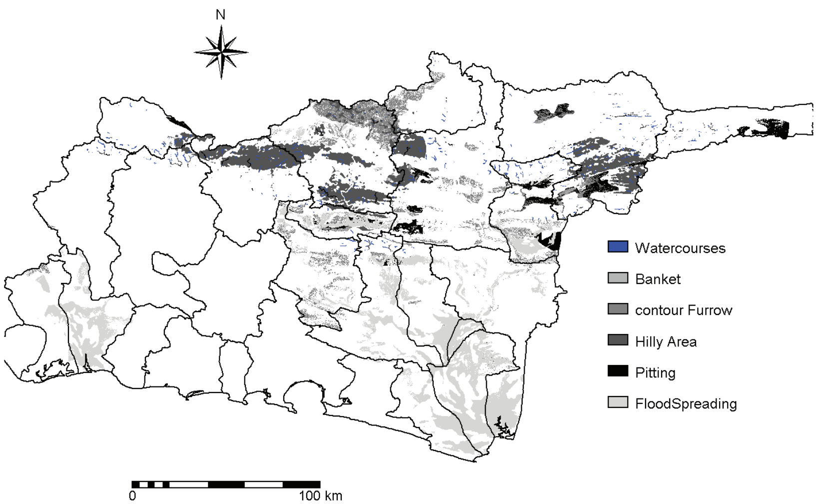

Fig. 3 - Location of suitable regions for RWH in the study area

RWH potentials for hilly areas. The suitable places for this type of RWH should satisfy the following criteria:

a) Low permeability (Mountainous and hilly parts of landuse map)

b) Land slope > 20%

c) Annual precipitation > 200 mm

The runoff volume in these parts of the watershed could be stored by structures like Pond, small and low earth dam, and masonry dam based on available materials. The results of analysis for this type of RWH are illustrated in Figure 3 and Table 2.

Table 2. Cumulative area (km^2) of the hilly areas RWH potential in the study area

Plain	Area (km^2)
Pishin	44.6
Benet	15.1
Nikshahr	466.1
Ghasre Ghand	825.0
Fanooj	48.7
Rask&Sarbaz	255.0
Total	2152

RWH potentials in watercourses. This type of RWH is used to capture the runoff flowing through a natural water course with the help of structures like weirs, barriers, underground dams, and so on. The potential area is a function of the availability of sandy river bed, topography that allows construction of weirs, geology to suit storage structures, and the presence of local water users (UNEP, 2005). To locate the suitable places for this type of RWH the following criteria are considered:

a) Channels with ranks of 1 to 3 (according to the Strahler ordering)

b) Land slope > 20%

c) Annual precipitation > 150 mm

The results of analysis are shown in Figure 3.

RWH potentials for aquifers' recharge. Parameters like the slope of plain, alluvia's texture and thickness, the infiltration rate of surface layers, existing permeable/ impermeable layers, and the amount of rainfall or floods determine the volume and yield of an aquifer. In this research, data layers including slope, surface infiltration rate, transmisivity, the level of water table, and water quality (Ghermezcheshmeh, 2001) were used for detecting the suitable regions for artificial recharge. Table 3 shows the criteria used for selecting the suitable regions to recharge the aquifers in the study area. In the application of these criteria, by merging the classes of I to III, only two categories were used: suitable and unsuitable.

Table 3 - Criteria used for selecting areas suitable for aquifers recharge

Suitability	Class	Slope %	Infiltration (mm/h)	Trans-missivity (m^2/day)	Sediment thickness	EC mmhos/cm
Very suitable	I	0-2	>45	>900	80-120	<1000
Suitable	II	2-3	25-45	600-900	40-80	1000-3000
Moderate	III	3-4	15-25	300-600	20-40	3000-6000
Unsuitable	IV	>4	<15	0-300	<10	>6000

According to the criteria mentioned in Table 3, the conditions of the aquifers in the study area are given in Table 4.

To find the location suitable for flood spreading to recharge the plains, in the first step Quaternary units were distinguished in the Lithology map of scale 1: 250000 and classified as suitable and unsuitable via the criteria in Table 4. In the next step the slope map was overlaid on this map and regions suitable potentially for this type of RWH were illustrated in Figure 3 and Table 5.

Table 4 - Condition of planes with respect to artificial recharge

Plane	Alluvium quality	Thickness	Infiltration	Trans-misivity	Recharge in plain	Recharge in channel
Bir&Bandini	Unsuitable	Unsuitable	Unsuitable	Suitable	-	Suitable
Sergan&Tis	Unsuitable	Unsuitable	Unsuitable	Unsuitable	Unsuitable	Suitable
Pirsohrab	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable
Fanooj	Suitable	Unsuitable	Suitable	Unsuitable	Unsuitable	Suitable
Benet	Suitable	Unsuitable	Suitable	Suitable	Unsuitable	Suitable
Lash&Zarabad	Suitable	Suitable	Suitable	Unsuitable	Suitable	Unsuitable
Ghasre Ghand	Suitable	Suitable	Suitable	Suitable	Suitable	Unsuitable
Irafshan	Suitable	Unsuitable	Unsuitable	Unsuitable	Unsuitable	Suitable
Bahookalat	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable
Kahir	Unsuitable	Unsuitable	Unsuitable	Unsuitable	Unsuitable	Suitable
Rask&Sarbaz	Suitable	Unsuitable	Suitable	Suitable	Unsuitable	Suitable
Chahbahar	Unsuitable	Suitable	Unsuitable	Unsuitable	Unsuitable	Unsuitable
Pishin	Suitable	Unsuitable	Suitable	Suitable	Suitable	Suitable
Nikshahr	Suitable	Suitable	Suitable	Suitable	Unsuitable	Suitable

Table 5 - Cumulative area (km^2) of artificial recharge potentials in the study area

Plain	Area (km^2)
Bahookalat	1593.1
Lash&Zarabad	624.0
Pirsohrab	829.3
Pishin	189.3
Ghasre Ghand	204.4
Total	3440

3. CONCLUSIONS

Rain water harvesting is a useful tool to cope with water scarcity in arid and semi arid regions, especially in the face of climate change and global warming. There are some investigations to enhance the method of rain water harvesting as a decision making tool based on the data gathered from field. There is no robust algorithm that could address all types of RWH in watershed scale. This paper introduce a research that tries to find a robust and GIS based algorithm for finding suitable places for 4 important types of RWH. The case study was chosen in the South Eastern part of Iran (South Baloochestan) where people are highly inconvenienced due to water scarcity. In this regard, the developed algorithm for in situ RWH, hilly areas RWH, watercourse RWH, and Flood Spreading RWH showed consistent results, which are in agreement with the field findings and gives 25 percent of the study area suitable for water harvesting. Further investigations (discussed in another paper) showed that RWH in this area that receives its total precipitation in a few times in a year and in the form of devastating floods can be regarded as an efficient tool for water management and water supply, especially for agriculture.

Furthermore, the results of the present research show that the developed algorithm could be used as a useful guide in the reconnaissance phase to explore water harvesting potentials everywhere, especially in arid/semi arid regions, where the surface water is scarce and the ground water is the only trustable source.

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