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Water harvest- and storage- location assessment model using GIS and remote sensing

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Abstract

This study describes a globally applicable method to determine the local suitability to implement water supply management strategies within the context of a river catchment. We apply this method, and develop a spatial analysis model named Geographic Water Management Potential (GWAMP). We retrieve input data from global data repositories and rescale these data to 1km spatial resolution to obtain a set of manageable input data. Potential runoff is calculated as an intermediate input using the Soil Conservation Service Curve Number (SCS-CN) equation. Multi Criteria Evaluation techniques are used to determine the suitability levels and relative importance of input parameters for water supply management. Accordingly, the model identifies, potential water harvesting- and storage sites for on-farm water storage, regional dams, and soil moisture conservation.

We apply the model to two case-study locations, the Sao-Francisco and Nile catchments, which differ in their geographic and climatic conditions. The model results are validated against existing data on hydrologic networks, reservoir capacities and runoff. On average, GWAMP predictions of sites with high rain water storage suitability correlate well (83%) with the locations of existing regional dams and farm tanks. According to the results from testing and validation of the GWAMP we point out that the GWAMP can be used identify potential sites for rain water harvesting and storage technologies in a given catchment.

1 Introduction

Fresh water resources are often not efficiently used and regulated (Seckler, Barker et al., 1999; Ambast, Keshari et al., 2002). This paper contributes for a better understanding of water supply management options for mitigation of and adaptation to fresh water scarcity. In this study, we develop the first component for an integrated water management assessment framework. This framework combines (i) geographic

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analysis to capture the high spatial diversity of natural conditions, (ii) engineering analysis to depict possible harvesting, storage, and transportation options for fresh water and alternative irrigation systems, and (iii) economic analysis to determine the cost-efficient water management over time. The component presented here relates to the geographic analysis and involves a spatially explicit analysis model, hereafter referred to as Geographic Water Management Potential (GWAMP) model.

Most existing geographic decision support systems to delineate rain water harvesting potential use location specific input data in vector format (for example; Gupta, Deelstra et al., 1997) and, therefore face difficulties in integrating grid based Global Climate Model (GCM) simulations. Here, we develop a more compatible system using globally available input data in raster (grid) format to facilitate the integration of GCM simulations and other global model outputs. For example, input parameters such as average monthly precipitation can be readily replaced with data from GCM simulations. This compatibility is an important feature for the assessment of adaptation and mitigation strategies under changing climate. In addition, our approach offers a relatively fast, preliminary site selection for water infrastructure development and avoids the time-consuming manual location search.

Geographic information systems (GIS) techniques are increasingly used for planning, development, and management of natural resources at regional, national, and international level. They have been applied for the assessment of several water related environmental challenges such as soil erosion, degradation of land by water logging, ground and surface water contamination, and ecosystem changes (Jasrotia, Dhiman et al., 2002). Raes (1998) provides evidence for successful catchment management including reservoir system management, irrigation scheduling and risk management. Sharada, Kumar et al. (1993) studied the application of GIS in entire catchments for site prioritization with respect to soil conservation. The Soil Conservation Services-Curve Number (SCS-CN) method has been used and validated in determining the rainfall-runoff relationship (Jain, Das et al., 1996; Boughton, 1989; Hariprasad, 1997). The study by Sharada, Kumar et al. (1993) describes a composite map generation with

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geo-databases and the calculation of area statistics are prepared much faster and accurate. Ross (1993) integrated GIS into hydrologic modelling and found that it reduces the modeler's subjectivity in parameter selection.

In GWAMP, we consider the entire catchment as the appropriate spatial scope for water resource planning, development and management. And, we apply GIS techniques to identify and analyze water harvesting and storage potentials. We illustrate and validate the GWAMP assessment tool with the Sao-Francisco and Nile catchments. The water runoff is calculated using the SCS-CN method.

In presenting the methods and results of our study, we proceed as follows: Sect. 2 provides details on the GWAMP model structure. Section 3 contains background information on the watersheds for the two case studies. Section 4 summarizes the case study results and concludes.

2 Methodology

2.1 Geographic Water Management Potential Assessment (GWAMP)

The GWAMP model framework (Fig. 1) is built based on GIS technology, including three components: data input, data processing and model outputs. The first component loads and prepares the necessary input data. The data processing component applies defined functions to all grid cells and identifies the suitability for rain water harvesting and storage technologies. The output component provides suitable locations for different rain water harvesting and storage techniques. The rain water harvesting technologies considered here include moisture conservation techniques such as check dams, percolation pits, and stone terraces on agricultural farms or nearby. Water storage technologies include regional reservoirs and smaller scale farm tanks in agricultural areas.

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2.2 Multi criteria evaluation process

We use Multi-Criteria Evaluation (MCE) to identify the suitability of each grid cell for water harvesting and storage. The purpose of MCE is to investigate alternative choices in light of multiple, often conflicting objectives (Voogd, 1983) and to generate overall rankings of these choices (Janssen and Rietveld, 1990). To generate multi-criteria based rankings, we use the Weighted Overlay Process (WOP) feature of GIS employing two indices: Standardized Compound Weight Index and Suitability level Index (SL). The final rating for criteria constraints is obtained with Compound Suitability Index. The following sections describe the development of these indices in more detail.

2.2.1 Compound Weighted Index (CWI)

The comparative importance of input data parameters is calculated with the Compound Weight Index (CWI). Input data include raster maps, whereas each layer is a factor in the decision making (constrain layers). For each grid cell, all input thematic layer values are weighted based on the comparative importance of each factor. The criterion performance score for each thematic layer is standardized in order to enable inter criterion trade-offs and to allow the comparison of the alternate performance in a common scale (Jankowski, 2006). The weight index of comparative importance is calculated using a pair-wise comparison matrix method in the context of decision-making process identified as the analytical hierarchy process. The final score for each grid cell (i-th row and j-th column) is calculated by multiplying the criterion weight and criterion performance score. The score standardization is shown in Eq. (1).

$$\mathrm{SS}_{ij} = \text{ Standardized Score} \tag{1}$$

$$\mathrm{RS}_{ij} = \text{Raw Score}$$

$$\underset{i}{\mathrm{Min}}\,\mathrm{RS}_{ij} = \text{Minimum raw score}$$

$$\underset{i}{\mathrm{Max}}\,\mathrm{RS}_{ij} = \text{Maximum raw score}$$

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$\underset{i}{\text{Min}}\,\text{RS}_{ij}$ = Minimum raw score

The standardization forces the criterion score to be between a lower bound of 0 and an upper bound of 1. Through pair-wise comparisons associated with analytical Hierarchy Process, every possible pairing and the ratings are arranged on a 9-point continuous scale (Saaty, 1977).

In this study, relative importance-ratings are calculated for each constraining layer and two water supply aspects. Particularly, we generate a pair-wise comparison matrix for water harvesting (Table 1-a) and storage (Table 1-b) site selection.

The CWI is obtained for water harvest and storage structures concerning each constraining layer, by computing the principal eigenvector of the pair-wise comparison matrix (Table 2).

2.2.2 Suitability Level Index (SLI)

The suitability of a particular water supply management technology, for a given factor is described with the Suitability Level Index (SLI). The suitability levels for regional dams scaled from 1 to 9, based on the criterion defined by Gosschalk (2002) whereas the suitability levels for small-scale farm tanks are determined based on the criterion defined by Lewis (2002). Additionally, the suitability for check dams, percolation pits, stone terraces and roaded catchments are determined based on recommendations by Mbilinyi, Tumbo et al. (2005) and Prinz (1996). Suitability levels considered for regional dams are shown in Table 3.

2.2.3 Compound Suitability Index (CSI)

Finally, combining the information from Tables 1 and 2, the Compound Suitability Index (CSI) for i-th cell for t-th rain water harvesting or storage technology, CSI_{ti} is given as in Eq. (2).

$$\text{CSI}_{ti} = \left\{ \left(W_{\text{RO}} \times \text{SL}_{\text{RO}_{it}} \right) + \left(W_{\text{S}} \times \text{SL}_{\text{S}_{it}} \right) + \left(W_{\text{TS}} \times \text{SL}_{\text{ST}_{it}} \right) + \left(W_{\text{SD}} \times \text{SL}_{\text{SD}_{it}} \right) + \left(W_{\text{LU}} \times \text{SL}_{\text{LU}_{it}} \right) \right\} \quad (2)$$

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Where:

W_{RO} = weight index for runoff layer for t-th technology;
W_{S} = weight index for slope layer for t-th technology;
W_{TS} = weight index for soil texture layer for t-th technology;
W_{SD} = weight index for soil depth layer for t-th technology;
W_{LU} = weight index for land cover/use layer for t-th technology;
$\mathrm{SL}_{\mathrm{RO}_{it}}$ = suitability level of i-th cell for t-th technology with respect to runoff;
$\mathrm{SL}_{\mathrm{S}_{it}}$ = suitability level of i-th cell for t-th technology with respect to slope;
$\mathrm{SL}_{\mathrm{ST}_{it}}$ = suitability level of i-th cell for t-th technology with respect to soil texture;
$\mathrm{SL}_{\mathrm{SD}_{it}}$ = suitability level of i-th cell for t-th technology with respect to soil depth and
$\mathrm{SL}_{\mathrm{LU}_{it}}$ = suitability level of i-th cell for t-th technology with respect to land cover/use.

The CSI is calculated for each grid cell within the catchment boundary with respect to each rain water harvesting and storage technology. The higher the index value, SCI_{ti}, the more suitable is a given grid cell for practicing the respective water harvesting or storage technology.

2.3 Input data parameters

The required input data for the GWAMP decision support system include data on elevation, soil depth, dominant soil type, land use and land cover, and mean monthly precipitation. We retrieve these data from global data repositories and rescale them to a 1 km spatial resolution to obtain a set of manageable input data. The data are extracted for the desired catchment boundary, entered into GIS, and processed into raster maps.

2.3.1 Elevation data

We use DEM (Digital Elevation Model) data developed using the method described by Reuter, Nelson et al. (2007). The DEM data are developed from 1-degree satellite

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images del. Hole filling is done by interpolation, concerning the size of the hole, and the landform that surrounds it. Inverse Distance Weighting interpolation is used in small and medium size voids filling in relatively flat low-lying areas. Spline interpolation is applied to small and medium sized voids in high altitude and dissected terrain. Triangular Irregular Network or Inverse Distance Weighting interpolation is used in large voids in very flat areas. Advanced Spline Method (ANUDEM) is used for large voids in other terrains. This seamless DEM data are downloaded from the CGIAR server (Jarvis et al., 2008) and data for each catchment was then extracted.

2.3.2 Contour data

First, we use the DEM raster surface to create contour lines in 10m intervals in raster (grid) format. Subsequently, we calculate contour density, i.e. the magnitude of contour lines per grid cell. The employed GIS algorithm considers the line segments that fall within a cell or its eight neighboring cells, in calculating the contour density. If the centre cell in the immediate neighborhood (3 × 3 cell window) does not contain contour lines, the output is assigned as "No Data". The density grid is reclassified into 10 sub classes and used as one input parameter in the GWAMP model. We use contour density data instead of elevation data, since it is more appropriate in data categorization within the model. For the identification of potential sites for regional dams, we combine additional knowledge based site identification step with the iso-line density data. This includes potential valley locations identification and screen from the suitable sites identified from the model.

2.3.3 Slope data

Slope data are generated from the DEM grid corresponding to the boundary of the catchment. The slope assignment corresponds to the maximum change in elevation between a cell and its eight neighbors, i.e. the steepest downhill gradient for a grid cell on a raster surface. The slope is expressed in degrees ranging from 0 to 90. If

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any neighborhood cells are No Data, they are assigned the value of the center cell and slope is computed. The slope (percentage) data is then classified into seven categories according to FAO guidelines.

2.3.4 Land use and land cover data

While land cover describes the physical material at the earth's surface, land use refers to the associated human activity. The dataset used here was developed within the LADA project (Land degradation Assessment in Dry lands) by the Land Tenure and Management Unit of the Food and Agriculture Organization of the United Nations (FAO/UNEP GEF, 2008). This hybrid approach results in both land cover and land use being mapped together with a spatial resolution of 5 arc minutes or 0.083333 decimal degrees. This input is the principle factor for the determination of the water runoff yield and the evaporation from the considered land unit.

2.3.5 Soil type and soil depth data

The infiltration rate of the soil determines the type of structure to be located and the surface runoff potential also depends on the soil texture of the area (Jasrotia, Majhi et al., 2009). We derive the soil texture attributes based on the dominant soil type map extracted from the Harmonized World Soil Database (DSMW, 2009) with a spatial resolution of 5 × 5 arc minutes. The soil class attributes are taken from the World Soil Information (ISRIC). The soil depth map is a simplified version of the soil depth data from the FAO spatial data repository (FAO, 2007).

2.3.6 Runoff data

The model calculates the runoff for each grid cell using monthly precipitation, land use and the soil type. The Soil Conservation Service – Curve Number (SCS-CN) method is used to generate the runoff. The SCS-CN method was originally developed by the US Department of Agriculture, Soil Conservation Service and is documented in detail

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in the (National Engineering Handbook, 2001). We use following equations (Eq. 3 and Eq. 4) to calculate the runoff.

Direct runoff is computed using the following relationship (Hand book of Hydrology, 1972).

$$S = \frac{25\,400}{\text{CN}} - 254 \quad (3)$$

$$Q = \frac{(P - 0.3\,S)^2}{(P + 0.7\,S)} \quad (4)$$

where:

Q = runoff depth, mm

P = rainfall, mm

S = maximum recharge capacity of watershed after 5 days rainfall antecedent

$I_a = 0.3\,S$ (initial abstraction of rainfall by soil and vegetation, mm)

CN = Curve Number, CN is found out from the table (Mockus, 1964).

In the process of calculating runoff, the soil map is reclassified into four hydrological soil group types A, B, and C based on the infiltration and runoff generating potentials (Niehoff, Fritsch et al., 2002). According to National Engineering Handbook (2001) and Boorman, Hollis et al. (1995), the characteristics of the hydrological soil groups can be summarized as below (Table 4). The water runoff values represent the cumulative annual runoff amount (mm), for each grid cell.

All of the above mentioned input data are converted to Arc/Info grid layers in order to use them as inputs in GWAMP.

3 Case studies

To test and validate GWAMP, we apply the model in two catchments with diverse geographic and climatic conditions. These include the Sao-Francisco and the Nile catchment.

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3.1 Sao-Francisco catchment

The Sao-Francisco catchment is entirely located in Brazil. It covers 629 885 km^2 (Maneta, Torres et al., 2009) and is drained by the Sao-Francisco River and its tributaries. The river flows from south to north along 2860 km (Braga and Lotufo, 2008), crossing diverse climatic regions. The amount of rainfall varies from the wetter south receiving annual average rainfall of about 1400 mm to the drier north receiving only 600 mm. The terrain of the southern area is composed of steep rocky hills, with slopes ranging from 18% to 45% at altitudes between 227 and 1849 m a.s.l. The Northwestern and Southern areas contain high mountains. At medium altitudes, grasslands are common especially towards the western boundary of the catchment. Towards the Northeastern boundary, low lying pediplanes can be observed. Hard rock terrains are found in the western part of the catchment. The entire catchment is characterized by a few major vegetation types including croplands, shrublands, and riverine vegetation. Open shrublands and grasslands dominate the hilly slopes of the study area whereas the cultivated croplands dominate the lowlands. Most of the agricultural lands are used for crop and livestock farming. Cereals are usually grown as a sole crop or mixed/intercropped with legumes. In addition, several fruits are cultivated throughout the catchment. Dominant agricultural crops are maize, beans, green grams, bananas, sugarcane and vegetables. Current livestock farming involves cattle, goats, sheep and chicken. Only a few large scale irrigation systems exist in the catchment. Trees Matias (19.53 km^3) and Juazeiro (4.25 km^3) are two large dams constructed in the catchment (Maneta, Torres et al., 2009).

3.2 Nile catchment

The Nile is the longest river in the world, stretching north for approximately 6850 km from East Africa to the Mediterranean. However, only 20% of the entire catchment area contributes water to the river. With an area of 3 million km^2, the Nile catchment spreads over 10 countries and covers approximately 10% of the African continent.

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Most of the downstream area are located in arid or semiarid climate with little water flow contribution but large evaporation losses (Karyabwite, 2000). Most of the regions in the catchment are influenced by the north-east trade winds between October and May, which cause the prevailing aridity in most of the basin. Tropical climates with well-distributed rainfall are found in parts of the East African lakes region and south-western Ethiopia. Similar climatic conditions prevail over the extreme southern parts of Sudan which receive about 1270 mm of rain over a nine-month period from March to November. The maximum rainfall usually occurs in August. The Sudanese and Egyptian parts of the Nile basin experience rainless periods during the northern winter. However, during the northern summer, the southern parts and highlands of Ethiopia incur heavy rain, usually above 1500 mm. The Nile basin contains two mountainous plateaus. The Equatorial or Lake Plateau in the southern part of the Nile basin is situated between the two branches of the Great Rift. It is at an altitude between 1000 and 2000 m but with peaks of 5100 and 4300 m. This plateau contains the lakes Victoria, George, Edward (Mobutu Sese Seko) and Albert, all of which are gently sloped towards north at an average rate of one meter for every 20 to 50 km distance. The Ethiopian or Abyssinian Plateau is located in the eastern part of the basin with peaks rising to 3500 m. Egyptians live primarily of agriculture. They cultivate corn, barley, beans, onions, garlic and lettuces. Every year, the rising of the Nile in August and September fertilizes the fields bordering the river. The major determinant of the Nile's water balance remains the agricultural sector. Farmers pump ground water to irrigate their crops during the dry season. The Nile Basin includes several lakes and artificial reservoirs. Lake Victoria is the biggest African lake functions with the Owen Falls Dam. The Jebel Aulia Dam, with a capacity of 3 km^3, was built to improve the natural storage of the White Nile waters. The Roseries Dam was designed to increase irrigated agriculture and power generation in Northern Sudan. Lake Tana, with a surface area of 3673 km^2 is the largest lake of Ethiopia located in a depression of the northwest plateau about 1800 m a.s.l. The Khashm el Girba Dam was designed to provide alternative livelihood to 70 000 people displaced the rise of water level behind the High Aswan Dam. The Aswan High dam

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has a crest length of 3830 m and a volume of 0.0443 km^3. The Lake Nasser reservoir, which has a capacity of 169 km^3 impounds up the Nile about 320 km in Egypt and almost 160 km farther upstream in Sudan.

4 Results and discussion

4.1 Potential sites for rain water harvesting and storage

Potential sites for rain water harvesting and storage technologies in the Sao-Francisco and Nile catchments as estimated with the GWAMP tool are shown in Figs. 2 and 3, respectively. Note that the sites identified in these maps correspond to either high or very high suitability levels for all included water harvest and storage technologies.

For both watersheds, GWAMP allocates potential sites for regional dams close to valley in the centre of the catchment. Potential water harvesting sites occur predominantly in the mountainous regions of the catchment, whereas the farm tank locations are distributed throughout the catchment. This is due to the spatial variability in topographical features. For example, towards the catchment boundary (in both cases), topography is largely hilly and with less continuous drainage networking compared to central valley regions of the catchment. The estimated total area share of potential sites for different types of rainwater harvest and storage options are shown in Table 5. Areas suitable for regional dams and farm tanks comprise about one third of the Sao-Francisco catchment but only about one tenth of the Nile catchment (Figs. 2 and 3 and Table 5).

Among the considered water harvesting techniques, percolation pits, contour bunts, and roaded catchments achieve the same degree of suitability in both catchments. Suitable sites for stone terraces, however, appear only on a small fraction of land in both catchments.

Potential sites for rain water harvesting and storage technologies identified and shown in Figs. 2 and 3 reflect the specific suitability levels for individual factors and

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their relative weights. An example from water storage practices; the most suitable sites for regional dams are located close to the main river and have moderately undulated slopes (0–16%). The evidence of locations where reservoirs already exists agrees with model results. The results also agree with findings by Mbilinyi, Tumbo et al. (2005), who argue that water reserves are constructed close to streams with slopes where water can easily enter and exit by gravity.

Within the agricultural areas, suitable sites for farm tanks are located in places with moderately undulated to steep slopes (16–30°) and with loamy sand or loamy clay soils. Suitable locations for percolation pits are found in areas which combine moderately undulated slopes (5–10°) with clay, silty clay, or sandy clay soils. These characteristics agree with findings obtained by Prinz (1996). Relatively fine soils such as clay and silt have a high water storage capacity and thus are suitable for percolation pits.

According to Hudson (1987) and Jasrotia, Dhiman et al. (2002), stone terraces and check dams are usually built on steep slopes with unstable soils of coarse texture, low organic matter content, or steep slopes. This characteristic is depicted by GWAMP which places stone terraces and check dams on steep slopes within both catchments. Soils with high shares of small clay and silt particles have a larger effective surface area than those with larger particles, and therefore detain more water (Ball, 2001). This agrees with the model results on locating roaded catchments are mainly found on gently undulated slopes (2–5°) with clay, silty clay and sandy clay soils accompanying the farm tank areas.

Results are in agreement with findings by Stanton (2005) that areas with low to medium slopes together with high water holding capacity soils, like clay, silty clay and sandy clay are suitable for on-farm tanks with roaded catchments. The relatively low cost of constructing roaded catchments on gently undulating slopes compared to higher costs on steep slopes could is a contributing factor.

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4.2 Validation

Existing water management structures from the Sao-Francisco and Nile catchments can be used to test and validate the performance of GWAMP. Here, we test the parameterization used for developing the system on suitability levels and relative importance weights. Through validation, we assess the reliability of results by comparing them with existing dams and farm tanks. We employ two main strategies for the validation. As a first strategy, we calculate the percentage of overlap between the suitable area from the model results and the existing areas. The results are shown in Table 6. Most existing rain water storage technologies are found in areas classified by GWAMP as very high (54%) or high (30%) suitability. We only validate rain water storage techniques, because we did not find appropriate data for existing check dams, percolation pits, stone terraces or roaded catchments. The fact that most of predicted rain water storage technologies were found within the very high to moderately suitable classes and areas producing high runoff indicates that, the model can be used to predict potential sites for rain water harvesting and storage technologies.

As a second strategy, we consider the number of tributaries contributing to the selected locations for different water storage techniques. While the Nile catchment consists of tributaries up to six orders, the Sao Francisco catchment contains tributaries up to five orders.

Table 7 summarizes the percentage of tributaries contributing to different selected regions. We find that modelled dams are fed by higher rather than lower stream order tributaries which support the fact of locating the regional reservoirs in main rivers. On the other hand, farm tanks and percolation pits are fed by lower order streams proving the fact that they are in locations where water quantity can be managed easily.

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5 Conclusions

The application of GWAMP in the two case studies demonstrates its suitability to identify potential sites for rain water harvesting and storage. Furthermore, GWAMP can easily update suitability levels and weighted score of decision criteria on which the potential sites for rain water harvesting and storage are based. In addition, the information on identifying potential sites for rain water harvesting and storage has been used for the development and operation of water management programs. This study demonstrates the capabilities of using global data sets and Geographic Information Systems (GIS) in spatial analysis models.

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Table 1. Pair-wise comparison matrix for assessing the comparative importance of factors to rainwater harvesting (A) and storage (B) site selection.

(A)

	Runoff	LULC	Slope (%)	Soil type	Soil depth	Drainage
Runoff	1	9	9	9	9	9
LULC	1/9	1	7	1/5	1/3	1
Slope (%)	1/9	1/7	1	5	1	1
Soil type	1/9	5	1/5	1	1	1
Soil depth	1/9	3	1	1	1	1
Drainage	1/9	1	1	1	1	1

(B)

	Runoff	LULC	Slope (%)	Soil type	Soil depth	Drainage
Runoff	1	9	9	9	9	9
LULC	1/9	1	1	1/7	1	
Slope (%)	1/9	5	1	1/7	5	5
Soil type	1/9	7	7	1	7	7
Soil depth	1/9	1	1	1/7	1	
Drainage	1/9	1	1	1/7	1	1

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Table 2. CWI values for rain water harvesting and storage technologies.

Weight factor	Storage structures	Harvesting structures
Runoff (m^3)	0.545	0.450
LULC	0.114	0.032
Slope (%)	0.098	0.159
Soil type	0.098	0.285
Soil depth (cm)	0.084	0.032

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Table 3. SLI for different factors for identifying potential sites for dams/ reservoirs.

Factor	Suitability level				
	9	8–7	6–5	4–3	2–1
LULC	Shrubs and sparse vegetation	Bare lands and urban lands	Agriculture	Forestry and grasslands	Wetland and protected areas
Slope (%)	0–2	2–5	5–10	10–18	18–45
Soil type	Luvisols	Ferralsols/ Pheozems	Regosols/ Arenosols	Vertisols/ Acrisols	Cambisols/ Lithosols
Soil depth (cm)	100–150	100–150	100–150	150–300	< 100
Runoff ($m^3\,km^{-2}$)	0–2.50	2.51–4.83	4.84–11.38	11.39–27.28	27.29–79.12

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Table 4. Main characteristics of hydrological soil groups.

Hydrological soil group	Main characteristics
A	Sand, loamy sand or sandy loam soils with low runoff potential and high infiltration rates.
B	Silt loam or loam soils with a moderate infiltration rates.
C	Sandy clay loam soils with low infiltration rates.
D	Clay loam, silty clay loam, sandy clay, silty clay or clay soils with very high runoff potential and low infiltration rates.

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Table 5. Potential suitable area for different rainwater harvesting and storage technologies.

Rain water harvest/ storage technology	Sao-Francisco	Nile
	% Area	
Regional dam/reservoir	31.24	8.87
Farm tanks	28.74	8.70
Percolation pits	12.10	3.49
Contour bunts	11.64	8.30
Stone terraces	3.45	4.10
Roaded catchments	12.83	1.32

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Table 6. Suitability of locations obtained using the GWAMP compared to the existing structures.

Observed water storage technology	Very High	High
Regional dams/reservoirs	43.65%	34.13%
Farm tanks	63.44%	25.07%
Average	53.54%	29.60%

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Table 7. Suitability of locations obtained using the GWAMP.

	Nile						Sao Francisco				
	1	2	3	4	5	6	1	2	3	4	5
Dam	29	38	42	11	9	44	73	64	64	64	82
Farm Tanks	17	8	5	2	2	3	72	15	7	2	4
percolation pits	29	16	6	7	1	4	71	16	8	3	5

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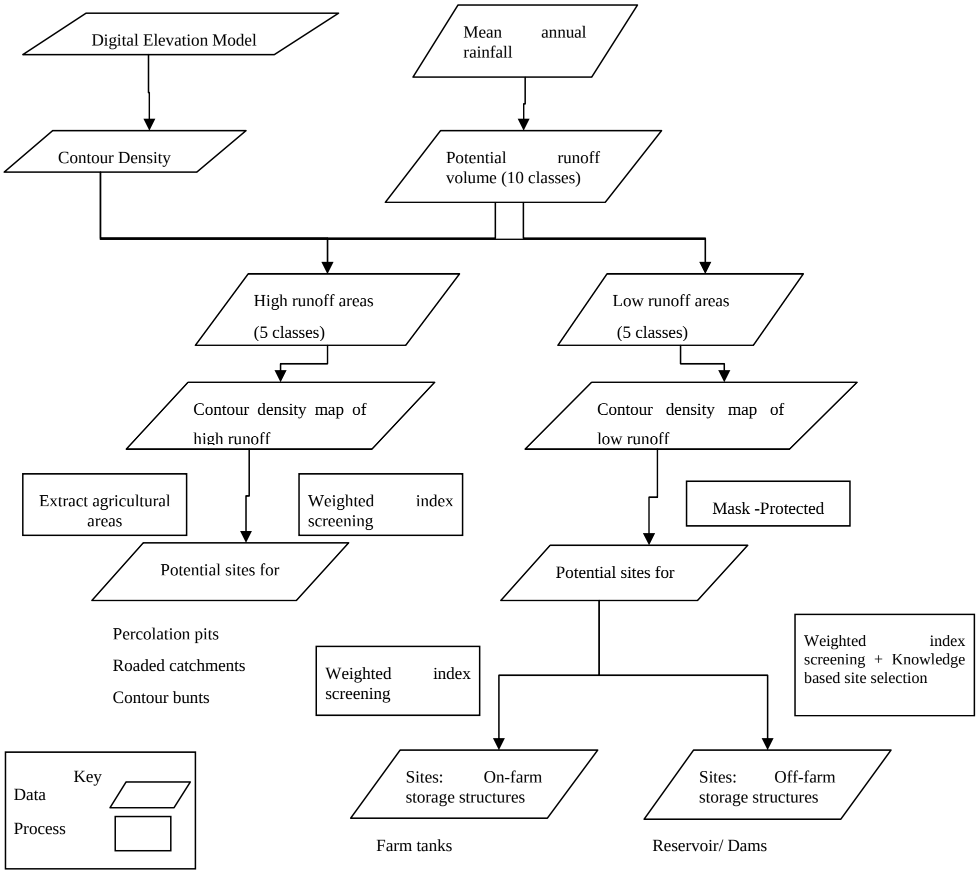

Fig. 1. Flow chart for identification of rain water harvesting and storage technologies.

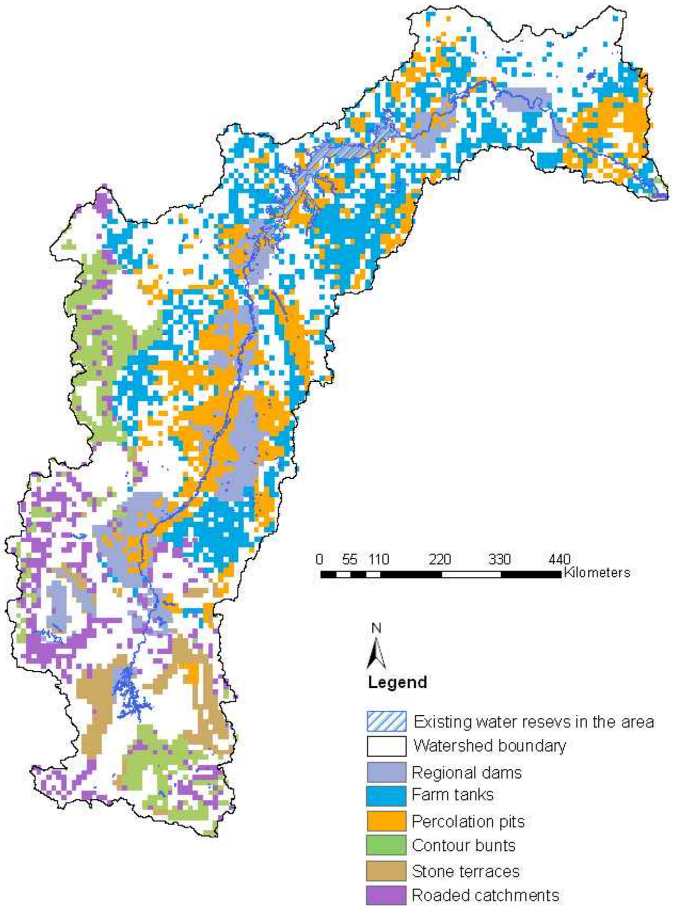

Fig. 2. Estimated suitable sites for rain water harvest and storage technologies in the SaoFrancisco catchment.

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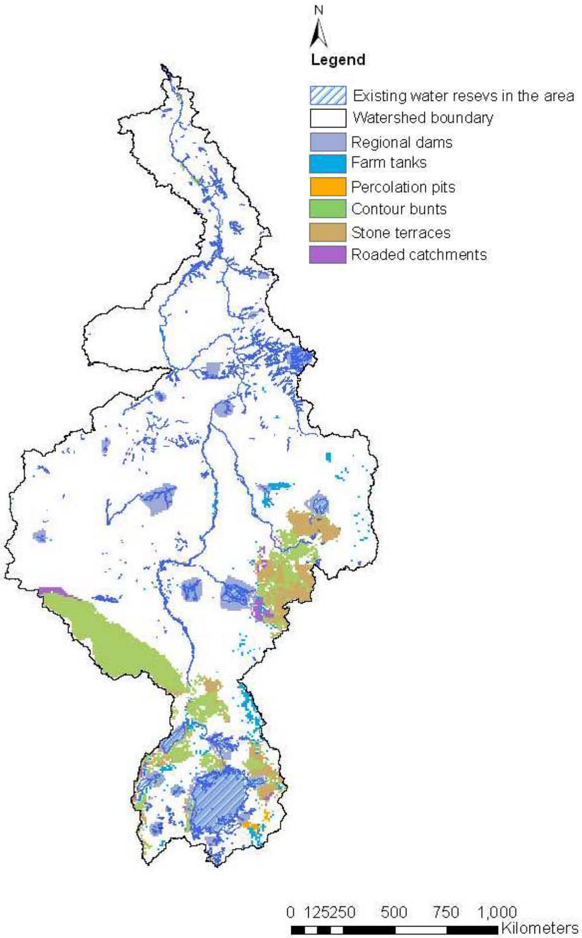

Fig. 3. Estimated suitable sites for rain water harvest and storage technologies in the Nile catchment.

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