Developing a GIS-based Suitability Map for Rainwater Harvesting in the West Bank, Palestine

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Abstract: In arid and semi-arid regions, the availability of adequate water of appropriate quality has become a limiting factor for development. Dry spells are a direct consequence of spatial and temporal variability of rainfall, and these jeopardize the replenishment of different water resources in the West Bank, Palestine. Rainwater harvesting (RWH) is an unconventional water source that is increasingly adopted in the West Bank. The potential of RWH (e.g. cisterns) to mitigate the spatial and temporal variability of rainfall has been confirmed in the region. Its implementation is promoted by local communities and non-governmental organizations to alleviate temporal and spatial water scarcity for domestic, crop and livestock production and support the overall water resources management in the West Bank. This paper aims to develop RWH suitability map for the West Bank. In this study, RWH suitability map is developed based on a combination of spatial weighted factors of landuse, soil, topography (slope), and runoff coefficient. Model Builder of ArcMap 9.3, that enables a weighted overlay of thematic datasets, is used to create the suitability map of RWH for the West Bank. Results indicate that about 40% and 11% are suitable and highly suitable for RWH, respectively. Details of the proposed method as well as the suitability map produced are presented in this paper. The implementation of the obtained results is envisaged to support any governmental policy shifts towards wide spread adoption of RWH in the West Bank.

Keywords: Rainwater harvesting; Geographic information system; Suitability map, West Bank.

1. Introduction

Rainwater harvesting (RWH) is a general term, which describes the practice of collection, storage, and use of rainwater runoff for both domestic and agricultural purposes (Siegert 1994; Gould and Nissen-Petersen 1999).

Gould and Nissen-Petersen (1999) categorized RWH systems according to the type of catchment surface used. These types are roof catchment systems, rock catchment systems, ground catchment systems, and check or earth dams. According to the type of catchment surface used, it is classified into infield RWH (IRWH), ex-field RWH (XRWH), and domestic RWH (DRWH). DRWH systems collect water from rooftops, courtyards, compacted or treated surfaces, store it in tanks (cisterns) for domestic uses. IRWH systems use part of the target area as the catchment area, while XRWH systems use an uncultivated area as its catchment area (Mwenge Kahinda et al. 2008). DRWH is widely practiced at household level in most of the West Bank rural areas.

In arid and semi-arid regions, RWH has been used for many years to enhance water productivity (for both agricultural and domestic uses) by mitigating temporal and spatial variability of rainfall (Boers et al. 1986; Bruins et al. 1986; Reij et al. 1988; Critchley et al. 1991; Abu-Awwad and Shatanawi 1997; van Wesemael et al. 1998; Oweis et al. 1999; Li et al. 2000; Li and Gong 2002; Rosegrant et al. 2002; Ngigi et al. 2005; Ngigi 2006; Oweis and Hachum 2006; Rockström and Barron 2007; Mwenge Kahinda et al. 2007a; Mwenge Kahinda et al. 2007b; Makurira et al. 2009).

Shadeed and Lange 2010 have confirmed the potential of RWH to bridge the supply-demand gap in the Faria catchment located in the northeastern part of the West Bank.

RWH is an ancient technology that is gaining popularity in a new way. Its history can be traced back to biblical times. Extensive rainwater harvesting apparatuses existed 4 000 years ago in Palestine and Greece (Evenari et al. 1971; Critchley et al. 1991). In India, simple stone rubble structures for impounding rainwater date back to the third millennium BC. This was also a common technique throughout the Mediterranean and Middle East. Water collected from roofs and other hard surfaces was stored in underground reservoirs (cisterns) with masonry domes (Agarwal and Narain 1997). On slopes, rural rainwater harvesting techniques have provided supplementary water for rain-fed agriculture in arid and semi-arid regions (Yair 1983; Giráldez et al. 1988; Tabor 1995; Lavee et al. 1997).

RWH is commonly used in Spain, northern Africa, and arid and semi-arid parts of India to meet the water needs of families and their livestock (Chapman 1978; Samra et al. 1996; Joshua et al. 2008). In arid and semi-arid regions, rainfall produces discontinuous runoff that in many cases never reaches the valley bottom. Therefore, suitable sites where runoff is produced are limited and relatively small (Lavee and Yair 1990; Brown and Dunkerley 1996). Lavee et al. (1997) have shown that rock outcrops produce runoff that tends to infiltrate further downslope in the colluvial mantle during the majority of events. These rock outcrops and thin, stony soils show a spatial distribution that depends on the topography and land use (Poesen et al. 1998).

In Western Europe, America, and Australia, RWH has often been the primary water source for drinking water. In all three continents it continues to be an important water source for isolated homesteads and farms (Agarwal and Narain 1997; Khastagir and Jayasuriya 2010). Recently, growing scarcity and intersectoral competition for water between all users in arid and semi-arid regions, along with groundwater depletion and problems facing major surface water control systems, have raised interest in restoring water harvesting systems that capture rainwater wherever it falls (Kerr and Pangare 2001).

RWH has various constructive benefits. It is inexpensive and highly decentralized, empowering individuals and communities to manage their water. It is environmentally safe and can be reasonably utilized. It provides a reliable renewable resource with special management and little investment. The harvested water can be transported with little energy. In agriculture, comparing to the 10% increase in food production from irrigation, RWH has demonstrated the potential of increasing food production by 100%. Generally, on 80% of the world's agricultural land area, rain-fed agriculture is practiced and it generates 65%-70% of the world's staple foods. For instance, in Africa more than 95% of the farmland is rain-fed, and almost 90% is rain-fed in Latin America (UNEP 2009).

FAO (2003, cited by Mwenge Kahinda et al. 2008) lists six key factors when identifying RWH sites: climate (rainfall), hydrology (runoff generation potential), topography (slope), agronomy (crop characteristics), soils (texture and structure) and socio-economic (population density, work force, people's priority, experience with RWH, land tenure, water laws, accessibility and related costs). A number of studies present methods for assessing RWH suitability of a given area. Those studies commonly use physical factors such as rainfall, land cover/use, soil characteristics and topography for the assessment of suitability. For instance, Mbilinyi et al. (2006) used rainfall, soil depth, soil texture, differential global positioning system points, aerial photos, ground truthing and topographic maps while Mati et al. (2006) used baseline thematic maps (rainfall, topography, soils, population density and land use) to produce composite maps that show attributes or ‘‘development domains” that serve as indicators of suitability for targeted RWH interventions. Mwenge Kahinda et al. 2008, developed suitability map for rainwater harvesting in South Africa based on physical, ecological and socio-economic attributes.

This paper presents a GIS-based model, which combines landuse, soil, topography, and runoff coefficient, to develop the suitability map for RWH in the West Bank, Palestine. The developed map will be of great importance to verify the adoption of RWH as one of the proposed water resources management options to bridge the supply-demand gap in the West Bank, which is an example of an area facing severe water scarcity.

2. Description of the Study Area

The West Bank, Palestine is located in the Middle East, west of Jordan (see **Figure 1**). It has a surface area of 5,640 km^2. The West Bank has a varied topography with ground surface elevations between 1,022 m above mean sea level in Tall Asur in Hebron in the south and 410 m below mean sea level near Jericho (adjacent to the Dead Sea) (UNEP 2003). The summits of the West Bank Mountains delineate catchment lines and the water divide separating the western and the eastern catchments. The Jordan Valley is part of a long and deep depression of the earth’s crust, widely known as the Jordan Rift, running along the edge of the country separating it from Jordan (ARIJ, 2000).

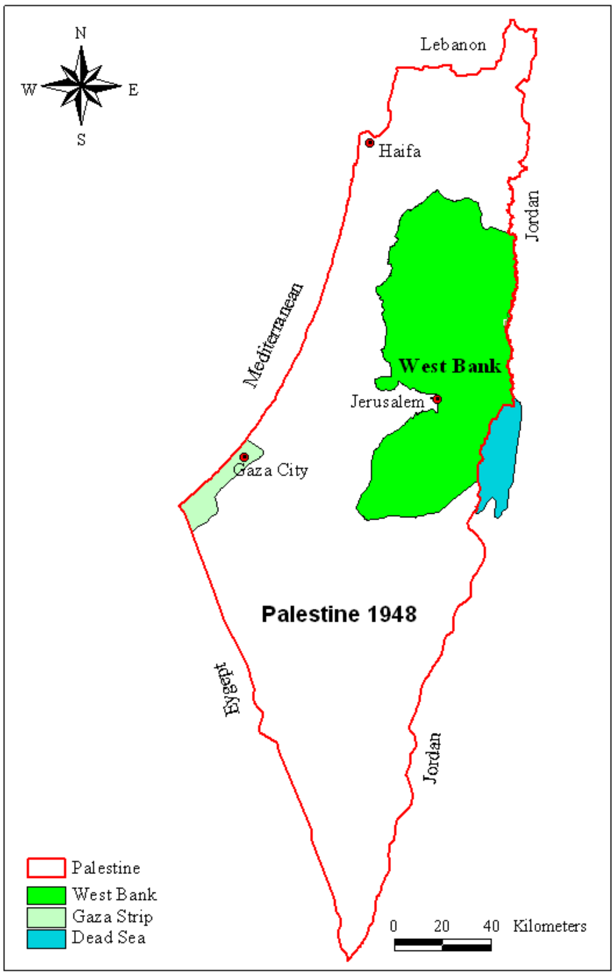

Figure 1: Regional Location Map of West Bank

The West Bank is mostly composed of limestone hills, brown lithosols and loessial arid brown soils cover the eastern slopes and grassland, with pockets of cultivation spreading over the steep slopes. Fertile soils are found in the plains. Soil cover is generally thin. Over all, about 12 percent of the land is desert, eroded or saline (UNEP, 2003).
The structural geology of the West Bank is dominated by a series of regional, parallel, southwest-northeast trending folds dissected by faults associated with the Jordan Rift Valley. The fault turns towards the northwest near Jericho. Some faults in West Bank act as conduits and some others represent barriers to groundwater flows.

In the catchments of the West Bank, surface runoff is mostly intermittent and constituted nearly 2.2% of the total equivalent rainfall (Rofe and Raffety, 1965).

The West Bank climate may be broadly described as a Mediterranean type, where it varies between hot dry in summer to wet cold in winter with short transitional seasons. Because of the wind, humidity, latitude and differences in altitude, there are considerable number of micro-climatic patterns. The area experiences extreme seasonal variations in climate. Large rainfall variations also occur from year to year. Consecutive years of relatively high or low annual rainfall have an enormous effect on the region and, in the case of dry years, present the greatest challenge to managing the region's precious water resources.

The rainy season usually begins in November and ends at the end of March. Rainfall is concentrated over a short period, with more than 60% of the annual rainfall commonly occurring in less than two months. Rain tends to fall in intense storms. This result in tremendous runoff during a few months and the country remains dry for almost the rest of the year. In general, rainfall is characterized by a high variation both temporary and spatially. In Nablus, for example, a minimum of less than 315 mm/season (1951/52) and a maximum of more than 1387 mm/season (1991/92) have been recorded, whereas the long term annual average is 642 mm. Rainfall decreases from north to south and from high to low altitudes. The yearly rainfall is as low as 100 mm in the Jordan valley, located in the rain shadow of the mountain ridge, to as high as 700 mm in the semi-coastal region.

The land cover map of the West Bank is classified into seven classes; built-up areas (5%), woodland/forest (0.7%), Israeli settlements (1.4%), arable land (14.31%), rough grazing (61.7%), irrigated farming (2.63%) and permanent crops (14.3%). Four soil textures exist in the West Bank; clay, clay loam, loamy, and sandy loam.

3. Spatial Data Layers

The best available datasets at national level of soil, land cover, DEM, and rainfall layers were first obtained and compiled in a GIS-based database (MoP, 1997). As the overall methods work in the raster environment with grid format layers, vector themes were converted into grid themes of cell size 25m×25m. **Figure 2** shows the average annual rainfall distribution in the West Bank. **Figure 3** depicts the land cover of the West Bank. Soil texture and slope are extracted from the soil and DEM layers respectively (**Figure 4** and **Figure 5**, respectively).

Shadeed and Masri 2010 derived a spatial distributed CN for the entire West Bank. From which the spatial distribution of annual runoff (**Figure 6**) was obtained using the SCS-CN method. For the purpose of this study, spatial distribution of runoff coefficient (RC) (**Figure 7**) for the entire West Bank is obtained by dividing the annual rainfall average layer by annual runoff layer.

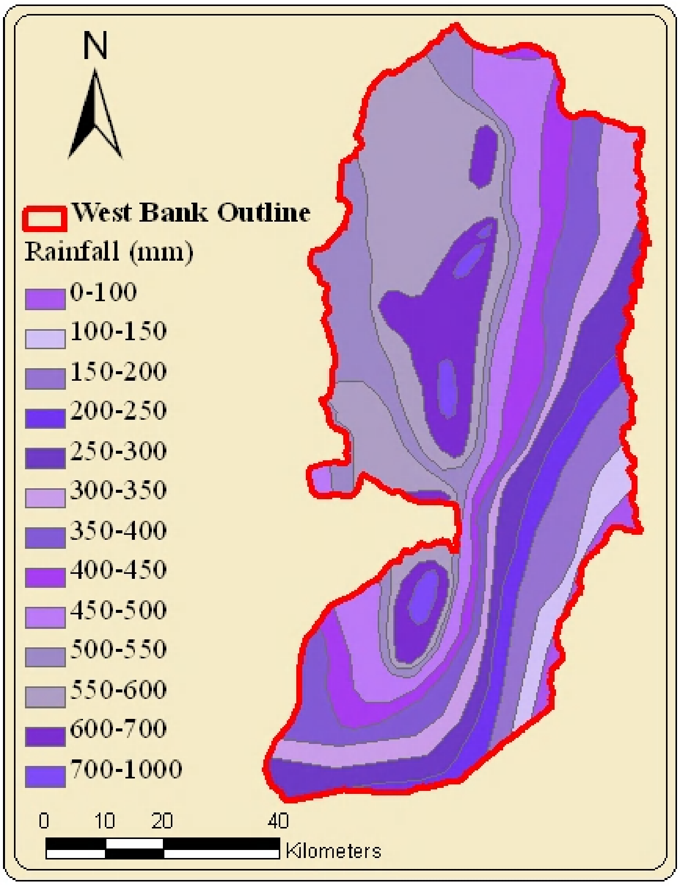

Figure 2: The Average Annual Rainfall Distribution in the West Bank

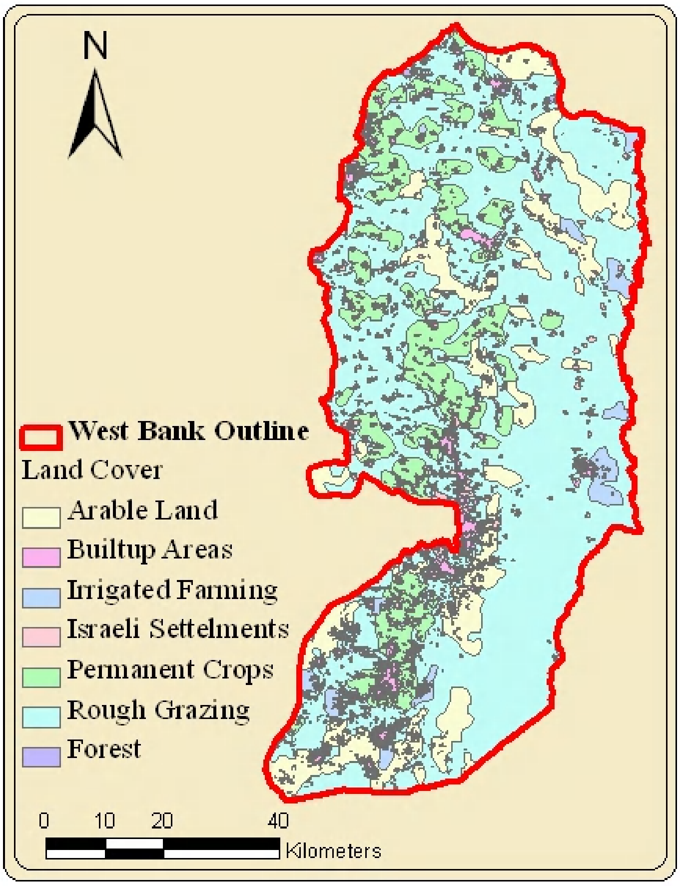

Figure 3: Land Cover Distribution in the West Bank

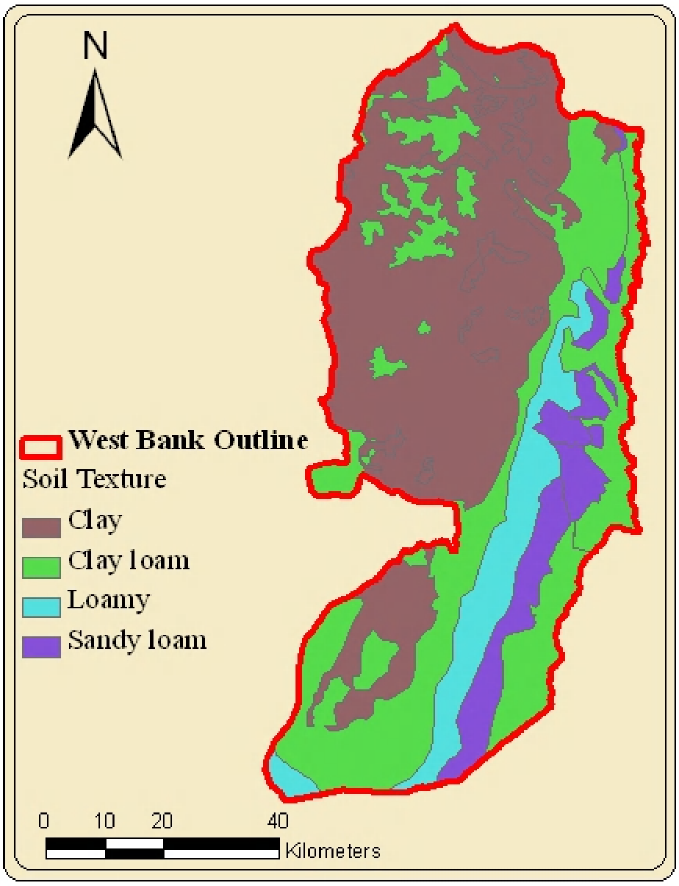

Figure 4: Soil Texture Distribution in the West Bank

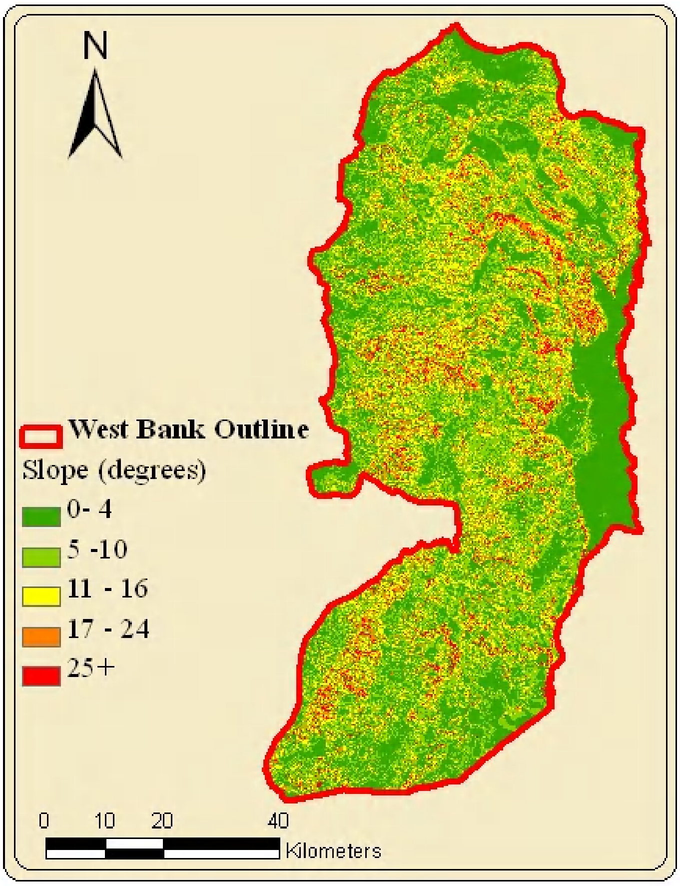

Figure 5: Slope Distribution in the West Bank

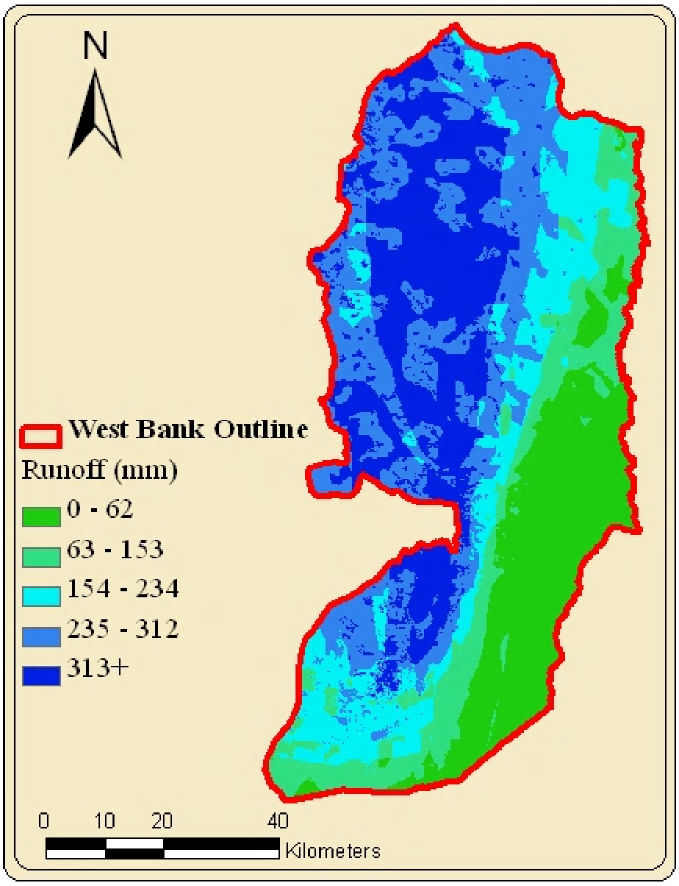

Figure 6: The Annual Runoff Distribution in the West Bank

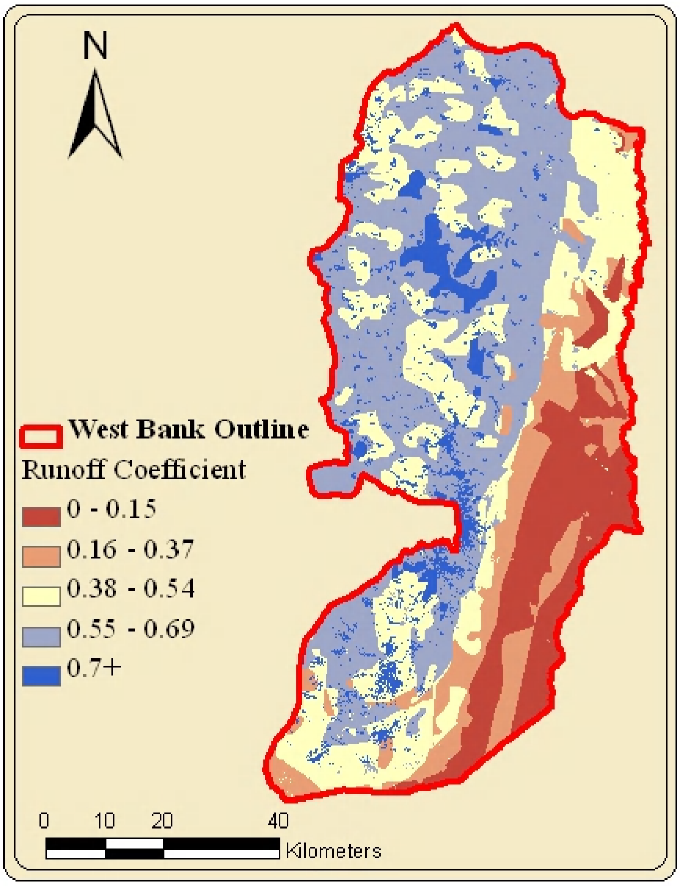

Figure 7: Runoff Coefficient Distribution in the West Bank

Different suitability values (weights) were subjectively assigned to the land cover (L), soil texture (ST), slope (S), and runoff coefficient (RC) layers. The weight of each layer reflects its importance in RWH potential. Assigned weights are as presented in **Table1**. The input layers (L, ST, S, and RC) classes in the dataset were ranked according to their suitability to RWH. User-specified cell values (suitability) of each layer were reclassified from 1 to maximum value equals the number of different classes for each layer as presented in **Tables 2** through **5**. The most suitable parameters to RWH were classified as the number of different classes, while the least suitable were classified as 1. To customize the development of RWH suitability map, the conversion to grid theme (with the same coordinate extent; Palestine 1923, Palestine Grid) and the reclassification was done during the data processing using Model Builder of ArcMap 9.3.

Table 1: Assigned Weights for Different Factors

Layer	Weight
L-Landuse	0.2
ST-Soil Texture	0.15
S-Slope	0.25
RC-Runoff Coefficient	0.4

Table 2: Land Cover Classes Suitability Ranking

Glass	Rank
Arable Land (supporting grains)	4
Built-up Areas	7
Irrigated Farming (supporting vegetables)	1
Israeli Settlements	2
Permanent Crops (grapes, olives, citrus, and other fruits trees)	3
Rough Grazing/Subsistence Farming	6
Woodland/Forest	5

Table 3: Soil Texture Suitability Ranking

Texture	Rank
Clay	4
Clay loam	3
Loamy	2
Sandy loam	1

Table 4: Slope (degrees) Suitability Ranking

Range	Rank
0-4	1
5-10	2
11-16	3
17-24	4
25^+	5

Table 5: Runoff Coefficient Suitability Ranking

Range	Rank
0-0.15	1
0.16-0.37	2
0.38-0.54	3
0.55-0.69	4
0.7^+	5

4. Developing the RWH Model

The chart of **Figure 8** depicts the overall methodology utilized in this paper for developing a GIS-based suitability map for RWH in the West Bank.

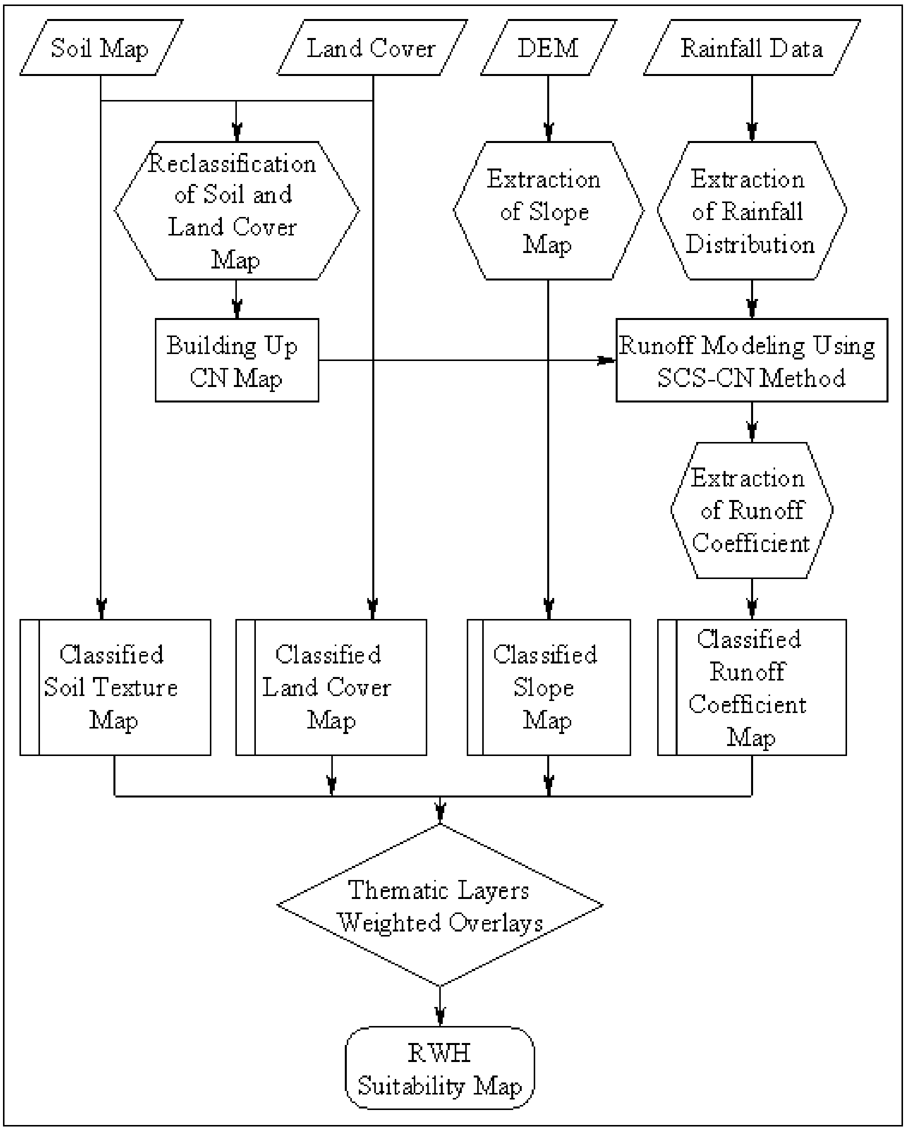

Figure 8: Methodology of the Study

Depending on the assigned input layer weights, RWH model was developed from a weighted overlay process (WOP) of the soil texture, land cover, slope, and runoff coefficient with different weights for all the layers (see **Table 1**).

The WOP allows the combination of data from several input grids by converting their cell values to a common scale, assigning a weight to each grid, and then aggregating the weighted cell values together. The WOP, also known as the multi-criteria evaluation is a weighted linear method commonly used in GIS-based decision making (Store and Jokimäki, 2003). Each layer is multiplied by its weight and the results are summed according to the following equation (Malczewski, 1999):

$$A_j = \sum_{i=1}^{n} W_i . S_{ij} \tag{1}$$

where A_j is the final cell suitability score index, S_{ij} is the suitability of the ith cell with respect to the jth layer, and weight W_i is a normalized weight so that $\sum W_i = 1$. The weights enable the solution to reflect the importance of the input layer relative to each other.

5. Results and Discussion

Based on WOP, RWH suitability map was generated. The developed suitability map indicates that the most suitable areas for RWH are mainly located in the western part of the West Bank (**Figure 9**). The eastern part was found to be the least suitable. This can be attributed to rainfall distribution in the West Bank which increased north-west and decreased south-east. Sparse of highly suitable areas are located in the middle mountains of the West Bank where also the rainfall is relatively high and thus the runoff coefficient (see **Figure 7**).

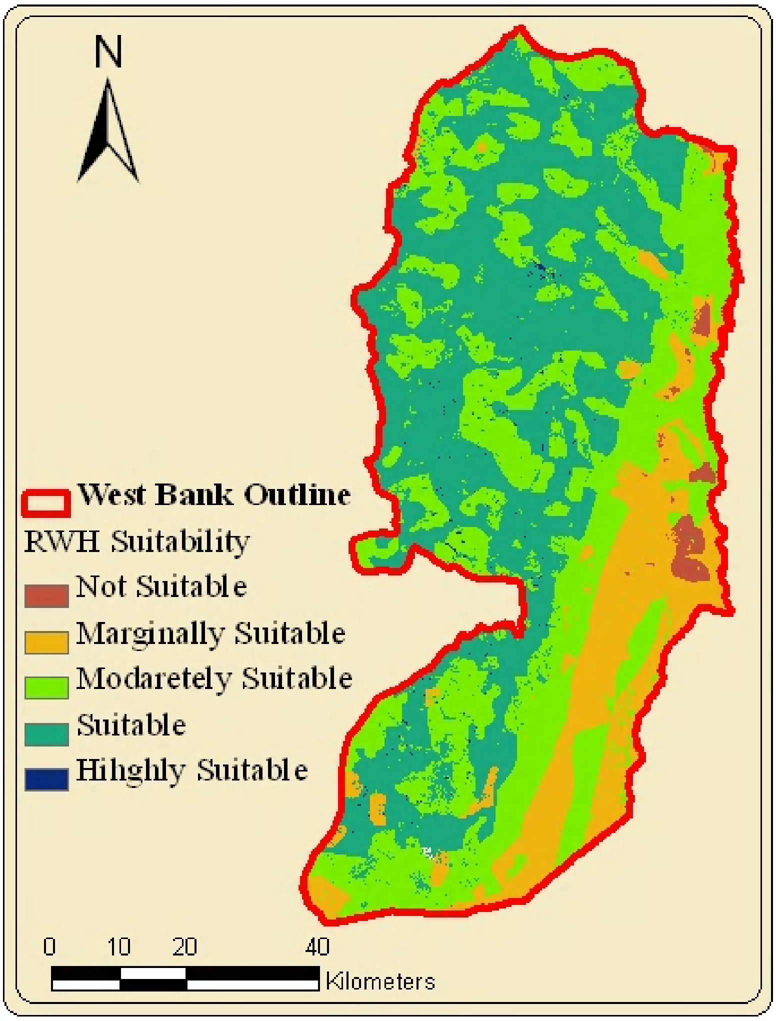

Figure 9: RWH Suitability Map for the West Bank

Table 6 presents percentages of RWH suitability for the West Bank. Based on **Table 6**, suitable areas were found to cover about 43% of the West Bank.

Table 6: Percentages of RWH Suitability in the West Bank

Class	%
Not Suitable	1.17
Marginally Suitable	15.34
Moderately Suitable	40.17
Suitable	43.09
Highly Suitable	0.23

6. Conclusions

The study aimed at developing a GIS-based RWH suitability map that indicates the areas of the West Bank suitable for RWH. The developed RWH suitability map combines through a WOP of the land cover, soil texture, slope, and runoff coefficient layers.

The major advantage of employing GIS in developing RWH suitability map is that a high degree of customizability can be attained. It enables the user to add, remove layers and change the relative importance weights of the layers. It should be noted that determining the weights is eventually a personal decision which is the best compromise among competing interests. It is therefore advisable to perform a sensitivity analysis by varying the weightings in order to provide insights into the generated RWH suitability map. The results should therefore be interpreted in terms of how the WOP can guide policy formulation. As with every modeling undertaking in the West Bank, the quality of the final results is influenced by the quality of the input data.

Considering the resolution of the datasets used in this study, its results are quite satisfactory for the West Bank to which it has been applied. The developed RWH suitability map do not have the required resolution to query details of known areas but it provides a country-scale valuable information for decision makers to develop and implement a strategy that guides the adoption of RWH in the West Bank. This will enhance the development of a comprehensive water resources management strategy to bridge the increasing supply-demand gap in the region.

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