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Mathematical Modeling of Rainwater Harvesting Systems for Upper Khanaqin in Diyala Governorate

A Thesis Submitted to the Council of College of Engineering University of Diyala in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering

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CHAPTER ONE

INTRODUCTION

1.1 General

Rainwater harvesting (RWH) is a method of collecting the runoff that occurs due to rainfall storms and flow on the ground surface to store it in earth, tanks, or small dams where it is utilised for a range of purposes. The infiltration of the rainwater plays an important role in recharging or feeding the ground water. The rainwater harvesting technique is antiquated, having been used since ancient times in dry and semi-dry regions throughout the world for agricultural irrigation, livestock requirements and for domestic use. Currently, due to the rapid growth of populations and the increased need for water, RWH is a topic of significant focus in recent studies. The collection of the rainwater is done either from rooftops where the water is usually clear with low contamination levels and is used for domestic and drinking purposes or by another method that attempts to collect water (run off) from the catchment area. This study will focus on the second method. As state by researchers, the water harvested from rooftops is specified as clean, so it is used for domestic consumption, whereas the water harvested from other catchments, especially in rural areas, has certain levels of contaminants and is therefore used for livestock, irrigation and for domestic supply after treatment **(Khoury, 2016)**.

1.2 The purpose of RWH

Many regions throughout the world experienced a lack of potable water and its remediation is expensive. RWH is a free and clean source of water and it only requires minor treatment before it become suitable for domestic uses. There are several benefits of using water that is collected through RWH such as it is more cost-effective, decreases the pressure on the sewer system by alleviating flooding, reduces soil erosion, supplement source for irrigation, and it replenishes and recharges the ground water **(Khoury, 2016)**.

1.3 Types of RWH models

There are several models that can be used to estimate and assess the runoff such as: TR55 (Technical Release 55), and the hydrologic modelling system, one of which is SWAT (Soil Water Assessment Tool), which adopted in present study. It is a scale model developed by Dr Jeff Arnold for the United States Department of Agriculture (USDA) Agriculture Research Service (ARS). The simulated hydrological cycle in the SWAT model is based on the following water balance equation which proposed by Chow (1964).

$$SW_t = SW^\circ + \Sigma^{t}_{i=1} (R_{day} - Q_{surf} - Ea - W_{seep} - Q_{gw}) \ldots\ldots\ldots\ldots\ldots 1.1$$

In the above equation, the final soil water content and the initial soil water content on day i, both expressed in mm, are respectively denoted by SW_t and SW^o; time is denoted by t and measured in days; the precipitation quantity, the surface runoff quantity and the evapotranspiration quantity (all expressed in mm) on day i are denoted by R_{day}, Q_{surf} and Ea respectively; and the water volume permeating the vadose zone from the soil profile and the return flow volume on day i (both expressed in mm) are respectively given by W_{seep} and Q_{gw}.

The surface runoff occurs when the rate of infiltration is less than the rate of water flow on the surface of the ground. The Soil Conservation Service Curve Number method (SCS-CN) (SCS, 1986) was used to estimate surface runoff using daily rainfall. SWAT simulates surface runoff volumes and peak runoff rates for each Hydrologic Response Unit HRU. The SCS-CN method was also employed in this study to estimate the surface runoff at the upper Khanaqin within the Diyala Governorate, which is located in north-east Iraq (upper Khanaqin) (Chow, 1964).

1.4 RWH Components

There are three components of RWH, which are detailed as follows (Bhawan & Nager, 2001):

1. Catchment area: this refers to the area from which the runoff will flow over and be collected. It may be the rooftop of the household and when the surface is impervious and smooth, the runoff occurs directly.
2. The surface characteristics: the runoff will be high where the surface is hard and smooth. A collection system is implemented to minimise losses, which generally includes a channel or pipe for collecting and conveying and a storage structure for storing the water until it is required for use. The collection system is installed in a way that the water is collected and moved to the storage structure by gravity. The storage system varies from a small tank to a small dam.
3. The utilization system: this is the system used for the management and collecting water. The utilization system varies depending on the purpose for which the harvested rainwater will be used. It typically consists of a distribution system to carry the water to the destination of use. The water is distributed either via a gravity-like channel, pipes and perforated pipes or by electrical means such as a pump. If the harvested rainwater is used for irrigation, the distribution system is included in the design of the collecting system to divert the rainwater to the required area (Linsley, 1988).

1.5 Statement of research problem

Due to lack of studies related to the RWH beside insufficient facilities in the area being assessed in this study to manage the water that is generated by all forms of precipitation such as runoff during the rainy season. Hence, this is a topic that needs to be comprehensively evaluated in order to enable the water to be used at a later stage, particularly during the dry season. Furthermore, additional research is needed to counteract the threat of the soil being significantly eroded by the substantial runoff.

1.6 Research objective

The objective of the study is to estimate average volume of runoff from the ungauged catchment area and proposed the suitable location to the storage structure using the SWAT model in addition to the future prediction of average runoff volume for the upper Khanaqin catchment area.

1.7 Research methodology

The following steps were carried out:

1. Collect the required data for the study, which includes a land use/cover map, climate data, a digital elevation model (DEM) map and a soil distribution map.
2. Apply the SWAT model to the study area with the input data.
3. Extract the result
4. Apply calibration for the SWAT model by using SWAT-CUP
5. Discuss the model output and suggest the storage structure (small dam) location (Ch5, 5.5.1).

The steps are shown in figure 1.1.

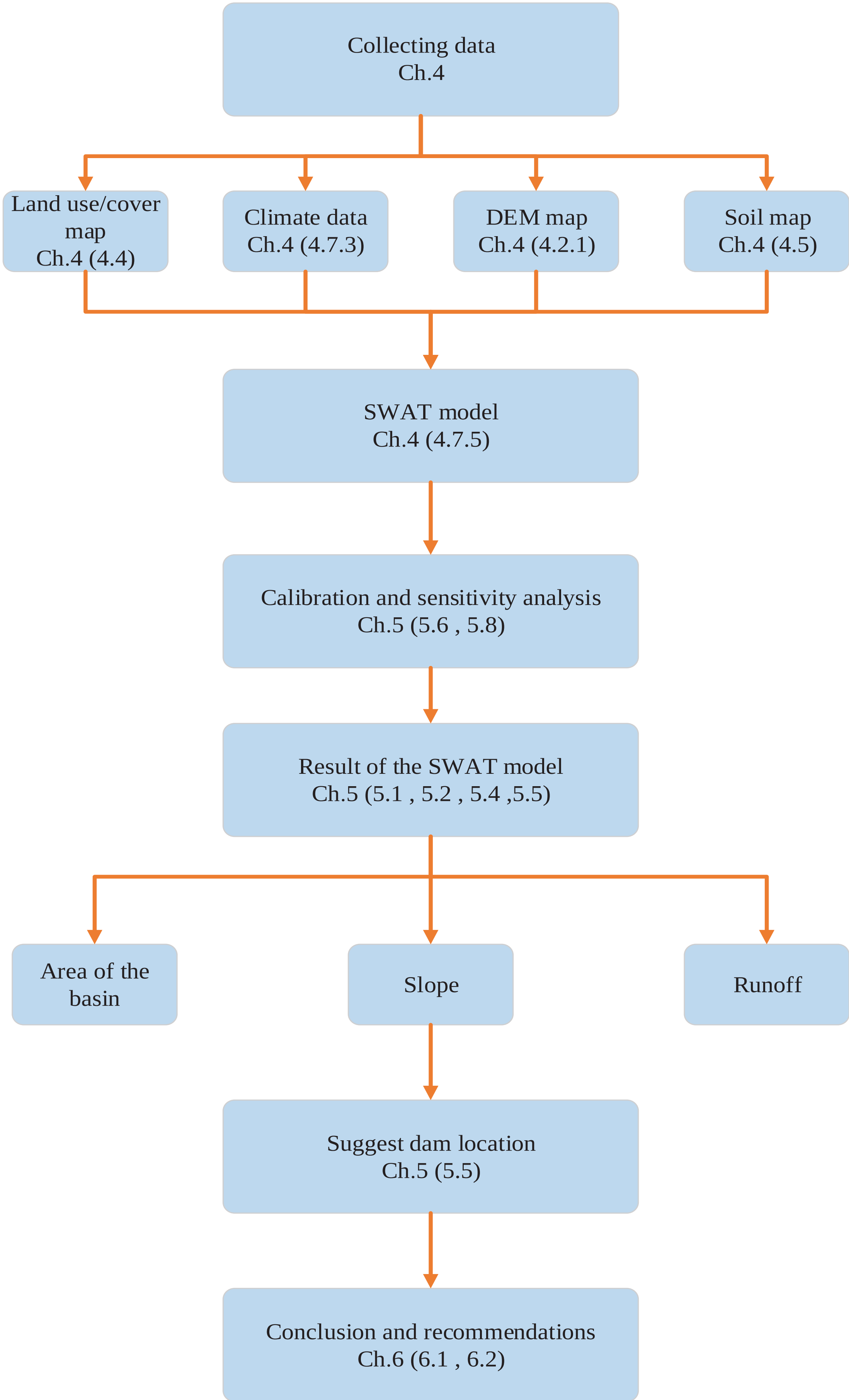

Fig. 1.1: Flowchart methodology of the study.

Mathematical Modeling of Rainwater Harvesting Systems for Upper Khanaqin in Diyala Governorate

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ABSTRACT

The rainwater harvesting system is an important component of arid and semi-arid countries due to its' essential role in reducing the growing gap between the need for water and its' scarcity and availability issues during dry seasons. The purpose of this study is to estimate the amount of surface runoff volume that can be harvested during flood seasons for use at other times. The location being evaluated (the upper part of Khanaqin city) was modelled using the mathematical model of Soil and Water Assessment Tool (SWAT). The catchment area of 701.836 km^2 was surveyed using remote sensing techniques and satellite images which include Digital Elevation Model (DEM) maps, land cover maps and soil maps of Food and Agriculture Organization (FAO). The results showed that the average volume of surface runoff for 21-year period from 1990 to 2010 is equal to (73,242,268.13 m^3). Furthermore, the predicted value of the average volume of surface runoff for 18 years during a period extended from 2018 to 2035 is equal to (76,352,348.53 m^3). The selection of the period from 1990 to 2010 for which the model simulation was conducted is due to the fact that the daily climatic data that has been used in the SWAT model simulation only available and extended within this period. It has been proposed as the site for the location of the dam for designing a system of irrigation relying on remote-sensing techniques and understanding the elevations and slopes of the topographic maps using the Geographic Information System (GIS) programme. As the proposed area had not been assessed, the neighbouring catchments' data was used in the SWAT-CUP

programme to calibrate the mathematical model. The calibration flow data used was dated from 2006 to 2010, and the validation test data was from 2010 to 2013, after treating it with the regionalization method (ratio method). The results show that the Nash-Sutcliffe Coefficient (NS) and the Coefficient of determination (R^2) for calibration and validation equal -0.05, 0.08 and 0, 0.04 respectively.