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Hydrological studies in the White Nile State in Sudan

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ABSTRACT

The present study was aimed to study the hydrological system in the arid areas of White Nile State, Sudan using remote sensing and GIS tools. Information on topography and soils had been extracted using ASTR, Digital Elevation Model (DEM), with 90 m horizontal resolution and Sudan General Soil Map with scale 1:25,000 using digitized method to form the GIS database. Land use/cover information was derived from remotely sensed data of Land sat Thematic Mapper of the year 2014. The vegetation cover was estimated using the normalized different vegetation index (NDVI). One sub-basin was delineated using a Digital Elevation Model (DEM) and the total acreage in different slope classes was estimated. These maps were used as input variables to derive a modified Soil Conservation Service (SCS) runoff curve number. The SCS runoff curve number model was applied to estimate the runoff depth for individual storm as (return period) event and summed up to derive the annual runoff potential for the sub-basin. All morphometric and hydrological characteristics for the elected sub-basin were extracted and illustrated and given in different tables, which include the stream numbers, the shape factor of the basin, the slope condition of the basin, the streams lengths, and the basin area and so on. The total surface water (runoff) in depth and volume potential for harvesting is 1.507 mm (depth) and 309,078.09 vol m^3. The results demonstrate the capability of GIS and its application for water harvesting planning over larger semiarid areas.

1. Introduction

Hydrology is multi-disciplinary research field that arises to investigate and manage water in different forms at different positions near or on the land surface. This definition is widely held, Chorley (1969), Clark (1976), Rodda et al (1976); Miller (1977), Raudkivi (1979), Viessman et al. (1989) and Maidment (1993). Irrespective of the growth of hydrology as a specialized science, hydrological research reflects different theoretical-empirical, pure-applied, micro-macro, system-operational, and geographical-non-geographical interests.

Generally speaking, hydrological research and modelling are interrelated. Most hydrological research concentrates on a modelling approach. The reasons are for a simplified, representative and logical presentation of a hydrological system. As well, most hydrological modelling endeavor depends mainly on the knowledge drawn from available measurements and experimental results. Hydrological models are often referred to as "hydrological system" (Raudkivi, 1979). Models of hydrological systems may be designed to explain and represent the behavior and relationships between the input and output of the system (Osman, 1996).

The typology of these models is broad and varying due to for example different types of modelling approaches. Hydrological models can be parametric (e.g., statistical regression techniques), analytical (systems analysis) or mathematical (physical analysis). Further, these models can be either stochastic conceptual, stochastic empirical, deterministic conceptual or deterministic empirical. The models can be systematically stored as linear or non-linear models, or spatially classified as lumped models or distributed (probability or physical) models Harvey (1969), Raudkivi (1979) and Osman (1996).

GIS as a system can performs many tasks that are necessary for a large number of environmental modelling procedures. These include terrain analysis, multilayer modelling, tabular data analysis, network analysis, areal analysis and image and graphic display of results. GIS as a spatial tool and a method is used in a broad spectrum of research fields including hydrology (McDonnell, 1996).

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Several researchers have utilized GIS and RS data for water resource management and hydrological modelling.

The characterization of the water balance during a major flooding events is useful to scientists, land use planners, and government agencies who need such information to develop strategy for coping with future flood and then for water harvesting potential, using water harvesting techniques and strategies (Mizgalewicz et al., 2003). Recent technological developments in the form of computer mapping and analysis database have provided the means to accurately analyze flood related data sets, such as stream flow and precipitation measurements, over extended periods of time.

Water movement within the drainage basin can be modelled. Important application of this emerging field of spatially distributed hydrological modelling tools include studies of soil types, impact of land surface (e.g., agriculture and forestry) management practices on hydrological regimes, impact of vegetation and land use change on hydrological regimes, and other land surface process. White (1998) used the SCS model for runoff potential estimation after combining the information of hydrologic response units including soil and land use and land cover for a large drainage basin in Pennsylvania with daily rainfall data using a GIS. The runoff depth on a cell by cell basis was estimated for ten actual storm events and summed up for the entire basin to predict the total runoff depth for each event. Stuebe and Johnston (1990) used GRASS, GIS, to predict the runoff volume for six basins using the SCS runoff curve number model. Information about elevation, soils, land cover and rainfall was stored in a GIS environment for drainage basin delineation and runoff estimation.

There are several factors effects surface runoff in north Africa and Mediterranean regions such as Land-use change, people relocation in urban areas, grazing abandonment inland as they affect water storage capacity (Abu-hashim et al., 2015).

Surface runoff as a process depends on rainfall characteristics and ground condition. Many theories have been formulated to explain the runoff process in relation to rainfall and surface variation at a place for a given time. Ranging from simple to complex, the models based on these concepts incorporate a number of input parameters. Respectively, the physical condition of a particular hydrological environment influence the attributes used in parameterization; in other words the parameters used to model particular basin or catchment area may influence positively or negatively in the amount of water can be harvested Therefore, the SCS runoff model was suggested to be applied in this research paper to estimate the surface runoff depth and volume. This study investigates the use of geographic information system (GIS), remote sensing data, in addition to field work data, soil data, and meteorological variables to be used as hydrological parameters for the purpose of hydrological model events in arid and semi-arid lands. The study encompasses one catchment area which located inside White Nile State.

2. Research objectives

The aim of this scientific paper as the followings:

a) To outline the design of distributed models in a GIS environment and to discuss the use of remotely sensed data as an aid in modelling hydrological process.
b) To develop, demonstrate, and document procedures used to model the water balance, for some of Wadies in arid and semi-arid areas (White Nile State).
c) To estimate rain water harvesting potential using remote sensing (RS) and GIS in order to advise a water harvesting strategy in arid and semi-arid environment.

3. The study area

3.1. Location

A sub-catchment area of Wadi Abu Hileify was considered for this study. The sub-catchment area lies within the White Nile State, Sudan which encompasses 209.09 km^2. The study area extended between 15°.277–15°.16 N and 32°.182–32°.207 E (Fig. 1). The study area lies within the drainage system of the river Nile basin system. Most of the water courses (Wadis) are ephemeral streams which flow during a short period after the rainy season.

3.2. Topography and drainage

Generally speaking, the topography of the study area is characterized by gently plains of low relief with an average altitude ranging from 374 to 483 m (Fig. 4a and b).

3.3. Climate

The climate in the region is characterized by a significant dry season from November to May, which sometime extends in dry years up to June. The average annual rainfall in the region is 922 mm. In contrast to that, the average annual rainfall in the selected study areas for the period from 1985 to 1993 was only 655 mm. So this area is prone to water scarcity and thus, drought-like conditions prevail. According to Walter (1971) an arid region is one in which the plants suffer from lack of water as the result of low rainfall and high evaporation throughout the longer part of the years. Thus, plant cover is only sparsely developed and shows various adaptation to the unfavorable water conditions. The separation between arid and semi/arid regions is made when the annual evaporation from an open water surface exceeds the annual rainfall. The evaporation ratio (E/P, the ratio of annual evapotranspiration to precipitation) as a function of the ratio of potential evaporation, E_0, to precipitation (E_0/P) commonly known as the aridity or dryness index (Φ) after Budyko (1974). Regions where aridity index is greater than unity are broadly classified as dry since the evaporative demand cannot be met by precipitation. The aridity index may also be related to climatic regimes in a broad sense, e.g. arid, semi-arid, sub-humid, and humid regions are defined by the aridity index ranges of $12 > \Phi \geqslant 5$; $5 > \Phi \geqslant 2$; $2 > \Phi \geqslant 0.75$; and $0.75 > \Phi \geqslant 0.375$, respectively (Ponce et al., 2000).

According to these, the study area full within the arid regions where the aridity index is $12 > \Phi \geqslant 5$.

3.4. Vegetation

The study area is sparsely vegetated as a results of the low amount of rainfall. The vegetation is exposed to extreme conditions and must survive drought, which can stretch over several years with little or no rain at all (Schmidt and Karnieli, 2000). According to the field visit conducted during the year of 2014–2015, it have been seen that, the vegetation cover formation is sparse dominate by *Acacia tortilis*, and *Maerua crassifolia.* Some part of the study area the vegetation is higher and denser. Trees and shrubs are disturbed alternatively with open grassland.

3.5. Water resources

The sources of water in White Nile state can be classified as rainfall, surface water and ground water. The study area suffers from an acute annual deficit in its water balance. Most of the rain water falls between July, August and September in form of heavy storms of short duration. The potential evapotranspiration exceeds the total precipitation. The greater part of this deficit occurs during