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Introduction

Water has been considered as an essential element for human survival and for that matter for the entire living organism. A quick review of water activities around the global clearly indicates that this resource has rapidly become one of the critical elements in determining local, national and regional growth. Water resources, while renewable, are limited. Water scarcity has recently been considered to be a major concern of those who are already facing the crisis.

The increasing population will have a direct and significant impact on future water availability, use and quality. The global trend of high growth rate of population indicates that over 90 percent of future population increase will be in developing countries, where access to clean water and sanitation services are inadequate. In Yemen according to the population projection for 1999, the total resident population was estimated at 17.7 million inhabitants, with annual population growth rate of 3.5 percent (Statistical Year-Book, 1999). By the end of year 2013, the population in the country projected to get doubled.

Because the total amount of fresh water is fixed, these growing populations will continuously reduce the water availability per capita. The Arab region is characterized by its water resources scarcity. The available surface water was estimated at about 204.62 billion cubic meters (BCM) and ground water availability for agricultural and municipal uses was estimated at about 35 BCM (League of Arab States, 1994).

Yemen faces such severe water shortages that it could be classified as one of the most water-scarce countries in the world. The situation is expected to worsen in the near future because of increases
in demand resulting from changing life styles, economic development and population growth. Agriculture depends entirely on the nature of the rainy season, a situation that makes the economy of the country vulnerable to even slightest climatic fluctuations. Therefore, any change in the patterns of rainfall may cause serious problems to the country. About two thirds of the population lives in rural areas and derives its main income from agriculture. The economic situation of this majority group is influenced heavily by the scarcity of water resources, which is expected to support the cultivation of approximately 1.1 million hectares, most of it depending on rainfall.

Yemen has predominantly arid to semi-arid climatic conditions with rainy seasons mainly during spring and summer (pre-monsoon and monsoon seasons) and with high temperatures prevailing all through the year in low altitude zones. The country experiences wide fluctuation in rainfall. Annual rainfall increases from less than 100 mm along the Red Sea coast (Tihama coastal plain) to about 500-1500 mm in the central highlands, particularly around Ibb area (1917.7 mm). However, in the further east the rainfall decreases and reaches 100 mm/yr in the Rub al Khali area. The country experiences chronic water shortages. There is substantial imbalance between the available water resources and the demand. In 1995, total annual renewable water resources were estimated at 2500 million cubic meters (MCM), with surface water amounting to 1000 MCM and groundwater contributing the remainder 1500 MCM. (Statistical Year-Book, 1999).

In the same year, total water consumption was estimated at about 3200 MCM. Thus, the water deficit between renewable water resources and water consumption was 700 MCM. According to the National Water Resources Authority (NWRA) (1998) the water deficit is expected to increase to more than 920 MCM by the year 2005. The water deficit has mainly been met by the accelerated use of ground water resources. Thousands of wells have been drilled to supply water
for agriculture and to meet the water demand of the ever-increasing population, particularly in urban centers. However, the uncontrolled pumping of ground water has resulted in declining water tables and increasing water salinity in the coastal areas where seawater has intruded into the fresh water aquifers.

**Rationale of the Study**

Wadi Zabid basin (the study area), with a catchment area of 5257 km$^2$, is the second largest stream that drains to the Red Sea. The Tihama Plain part of the study area is one of the most promising areas for the recent and future agricultural development in Yemen due to its agricultural potential and the richness of groundwater resources, compared to other regions. However, the water resources have been improperly managed. There are reduction in total runoff, as a result of variation in climate conditions, and increasing demand for agricultural activities that has been placing more pressure on water resources. The declining water table levels at alarming rates and increasing salinity, particularly in the coastal zones. All these call for the need of proper management of water resources of the study area for which knowledge of the basin characteristics particularly related to hydrology and terrain conditions of the wadi is essential.

**The Study Area**

The area of this study is Wadi Zabid basin. The Wadi basin lies in western Yemen and drains into the Red Sea. It extends from the Yemen Highlands in the east to the Tihama coastal plain in the west. The Wadi basin lies between longitude 43° 5' and 44° 20' east and latitude 13° 45' and 14° 30' north. With a total of 212 km, Wadi Zabid and its tributaries drain a catchment area of 5257 km$^2$. Based on altitude and relief, the area of the wadi basin has been divided into three physiographical zones. From east to west, these zones are: (1) the eastern zone (highlands), (2) central zone (midlands) and (3) western zone (Tihama lowlands). Elevation increases from sea level in the west
to more than 2800 m in the east. Geologically, the catchment area of Wadi Zabid lies on the Yemen Plateau that had been uplifted and tilted roughly westward. The Tihama Plain was down-faulted several thousand meters. It is situated inside the Red Sea Rift system. The vertical movement of the plateau created the escarpment that faces the Red Sea. Other major effect of the tectonic movements included the regional faults, most of them running parallel to the Red Sea, and the widespread volcanic activities. Some of the faults control the drainage system of Wadi Zabid. The rising of the magma led to the formation of extensive volcanic extrusive in Yemen including the upper catchment area of the wadi. The outcropping formations range from PreCambrian to Quaternary on the geological time scale. Yemen Volcanics (Tertiary) are dominant in the upper catchment of the wadi and Quaternary deposits are dominant in the Tihama coastal plain. However, old formations tectonically elevated, are also found in the transitions zone (Foothills) between the Tihama plain and the mountainous region of the basin. These formations include PreCambrian igneous rocks, Jurassic sedimentary rocks (limestone) and Cretaceous sedimentary rocks (sandstone).

The study area is very heterogeneous in terms of climate. The climate varies from arid to semi-arid on the Tihama zone and central zone respectively to sub-humid on the higher altitudes in the surrounding mountains in the eastern zone. Mean annual temperature varies between approximately 18°C in the highlands and 30°C in the Tihama lowlands. There is a gradual decrease in the mean temperatures from west to east with the rise in elevation. The Tihama lowlands can be identified as the hottest areas of Wadi Zabid basin. Mean annual rainfall decreases from east to west. Monsoon is the main rainy season. The highest and the lowest mean annual rainfall values are recorded at Ibb1917 mm (highlands) and Zabid Town 185 mm (Tihama plain).
Objectives of the Study

Several studies have been conducted on the issues of water resources development and management. Policies and recommendations have been made at the regional and national level. However, the Wadi Zabid basin (the study area) has not been studied separately in terms of wadi-specific integral water resources management. Moreover, with recent additions of hydrological data for sufficiently large period becoming available it is necessary to have a fresh look at available water resources and revise the earlier estimates and plan in light of the recent information. The author, therefore, thought of studying the surface water resources of Wadi Zabid basin with the following objectives:

1. To assess the total of the surface water resources of Wadi Zabid.
2. To understand and analyze the pattern of domestic and agricultural water resource utilization.
3. To look into spatial variation in the pattern of utilization particularly in agricultural sector.
4. To assess the validity of present utilization.
5. To evaluate optimal utilization pattern.
6. To identify and minimize the gap between optimal and present utilization.
7. To formulate a regional policy for water resources for the area under consideration.

Methodology

Since the overall objective of the present study is to evaluate the availability of water resources of the study area, and then to consider the optimum utilization, the research methodology has been formulated to serve this main objective. The research work has been carried out in three parts such as (A) climatic and hydrologic analysis, (B) terrain analysis, and (C) water resource availability- need analysis.
Approach

The present work has been divided into eight chapters. Chapter one discusses the availability and demand aspects of the water resources starting with the global view and goes down to the regional and national levels. The urgent need for water development and management, particularly in the developing countries, has been highlighted. The chapter contains the rationale of the study, the main objectives of the study and the methodology.

Chapter two includes the discussion about various aspects of water resources. The discussion includes topics such as the availability, demands and causes of the increasing demands. Other issue includes the international growing concern about the issue of water resources development and management. The discussion goes down to the national level and Yemen has been the focus in order to show the water situation in the country as well as in the study area. The chapter concludes with a brief review of previous work done in hydrology and water resources development in the country and the study area as well.

Chapter three deals with the general description of the study area. The aim of this chapter is to give general view of the physical characteristic of the wadi basin. The contents of the chapter include location of the area, physiography, geological setting, soils and natural vegetation.

Chapter four is devoted to analysis of the general climatic characteristics of the study area. The climatic parameters are analyzed in this chapter. Since the primary objective of this analysis is to assess the water availability, more concern has been given to the rainfall analysis, particularly, the rainfall analysis in space and time in order to estimate the areal mean rainfall and volume of available water. The
basin has six rainfall stations and two full-fledged meteorological stations. Data from these stations formed the base for the analysis of climate. The available rainfall data for the period of 30 years (1970-1999) has been used for the rainfall analysis. Isohyetal method, and Thiessen polygon were employed in order to calculate the average rainfall over the basin.

Chapter five deals with the terrain conditions. Terrain is one of the principal basin characteristics affecting stream flow. The morphological set up of the basin largely determines the water resource occurrence, distribution and management. Moreover, the understanding of the terrain conditions helps in suggesting the suitable watershed programme, which can be implemented in different parts of the wadi basin. Therefore, the analysis of the terrain was given more attention. The analysis of the terrain has been divided into three parts: (1) Physiographical analysis, (2) Slope analysis, and (3) Drainage network analysis. Based on topographical sheets (1:50,000) Digital Elevation Model (DEM) was developed for the Wadi Zabid basin. The basin has been divided into three zones and each has been described in details.

The slope of a drainage basin is an important variable, which not only shapes the geometry of the basin but also determines the development and management practices in the basin. Hence, the slope analysis of the Wadi Zabid basin was carried out. Topographical sheets (1:50,000) and aerial photographs (1:60,000) formed the database for this analysis. The purpose of the slope analysis is to understand the hydrological conditions of the basin which help in suggesting the methods of controlling the runoff for the benefits of recharging the groundwater and reducing the danger of the floods.

Some of the drainage characteristics have been analyzed. For the purpose of detail analysis, the Wadi Zabid basin has been divided into 8 sub-basins of the fifth and sixth stream order. Further, 59 basins of
the fourth order for their network characteristics. This has been useful for the watershed management part.

Chapter six deals with the quantification of water resources. The aim of this chapter is to analyze and determine the amount of available water that can be utilized in optimum ways. The analysis mainly focuses on spatial and temporal distribution of rainfall, quantification of volume of rainfall and estimations of runoff. The wadi basin has been divided into 8 polygonal areas. The rainfall volume in each polygonal area has been computed. The monthly records of rainfall available for a period of (1970-1999) have been utilized for understanding the rainfall distributions at different stations in each month. The mean, standard deviation and coefficient of variation (CV) for each of the month have been obtained. Dependability of rainfall as a source of water is generally analyzed with the help of frequency distribution and theoretical probability distributions. For this purpose the recurrence interval has been attempted for annual and seasonal rainfall with reference to each of the stations. For the present work depends on the concept of runoff zones suggested by the Technical Secretariat of the High Water Council (TS-HWC) of Yemen has been employed. Each of the polygon area has been divided into different runoff zones on the basis of terrain conditions prevailing in the area. With the help of the aerial photographs as well as other maps, 8 runoff zones have been identified in the basin. These are classified into absorbing (A1-A3) and producing (P1-P5) zones. With the help of statistical equations, the runoff volume in these zones has also been computed. In the absence of daily rainfall data, the mean monthly rainfall has been used for estimation of runoff for each of the runoff zone by using the CN values recommended by HWC. Runoff quantification has been attempted for normal as well as dry year conditions. The flow data within Wadi Zabid is available from Al Kolah Station, located in the downstream area. This is the only station
at which discharges as well as volume of flow are available. Flow as well as flood data from Al Kolah have been analyzed.

Chapter seven is devoted to the analysis of the water requirements. The water requirements for two water usages (domestic and agricultural) have been analyzed. Variables such as area of the districts, population, and crops have been considered and analyzed in order to understand the total need and the future demands. The analysis of the municipal and agricultural water requirements have been carried out. Ozla wise population has been used in the analysis of the municipal water requirements. Estimation of population has been made up to the year 2030 in order to understand the recent and future needs of water in urban and rural areas. The analysis includes area and water requirements in each Ozla as well as district. The effective and dependable rainfall in each polygonal area has been used for the water required by each crop. Water requirements for main crops as well as the livestock have also been calculated.

Chapter eight deals with constrain and limitations faced by the region in the water resource management. It also covers the topic such as region wise characteristics of the terrain, which have been responsible for the low level of agricultural extension. Each of three zones of the wadi basin has been discussed in details. Landscape sketches and extracts of aerial photographs have been presented for different parts of the basin. The purpose is to gives more and specific idea about the terrain conditions in each part of the basin. Three fourth order basins have been selected to explain the watershed management programme. These basins are representatives of the eastern, central and transition zones. An attempt has been made to suggest various means and methods of enhancing the scope of water resource management through the technique of rainwater harvesting.