USING NILE BASIN- DECISION SUPPORT SYSTEM (NB-DSS) FOR MANAGEMENT OF KHOUR ABU HABIL WATER RESOURCES

استخدام نظام حوض النيل المساعد في اتخاذ القرار لإدارة الموارد المائية بخور ابوحبل

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DEDICATION

To my mother and my father

To my sisters and my brothers

To all my friends and my teachers

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ABSTRACT

Being able to assess the hydrologic ability of Abu Habil catchment to satisfy its future water demands is crucial in order to plan for the future and make wise decisions. In this study a Scenario Analysis approach was used by utilizing NB-DSS model for water resource management, evaluation allocation and planning, in order to assess the impacts of possible future water demands on the water resources of Khour Abu Habil catchment. For each scenario, the main outputs of the model were analyzed: under water demands for the different water sectors and users, stream flows at the outlet of Khour Abu Habil catchment and the water possible to be stored in the reservoirs.

The NB-DSS model has been successfully applied in Abu Habil river basin and its sub-basins .In addition satellite data has been used to obtain (a) present agricultural practices, (b) available suitable land for agricultural, domestic (urban and rural development) and topography, land use and other variables and (c) satellite data for climate.

The Nile Basin Decision Support System (NB-DSS) is employed to provide an operative computer platform for decision makers, and is used for the evaluation of water management options and regional strategic plans. The NB-DSS comprises an information management system that performs data collection, verification, management, and visualization, and output from models estimated crop water demand (CROPWAT) for different levels of water use units. Water allocation between the various uses is simulated for a long time horizon using a deterministic model running on a monthly time step (for year 2030). The evaluation procedure of the NB-DSS was used to compare the effects of five options of strategic intervention plans of infra-structures (Construction of Haffirs, Three Dams, Turda Dam) on the basis of well-defined, comprehensive six indicators using multi-criteria approach by expressing the three major principles of Integrated Water Resources Management including: Water availability (Supply), Improvement in productivity of crops, economic (costs of development), impact and risk on downstream user, and environmental sustainability.

The objective of this study is to aid in the decision-making process related to evaluation of water management scenarios and plans and implementation of intervention options to aid real-time responses to changes in water supply, allowing future developments of watershed water resources to be based on the actual relationship between the supply and demand for water. The system is tested to allocate water to different levels of water use units as a standard decision support tool by means of the actual total available water and existing (base year 2012) and expected future situations (year 2030)

The model results and the analysis made show that: the runoff, if efficiently managed, should be enough to cover the water demands that range between 44361.88 Mm^3 in the current scenario and 55036.02 Mm^3 in the year of 2030.

The major shortages are registered in Um Tagerger where annual water deficits reach 10.7 Mm^3/year for the present conditions (2012) and increases to 12.9 Mm^3/year in future scenarios (2030). This is followed by Khor Kajeer which is 2.6 Mm^3 and goes up in future to 3.0 Mm^3. The water deficit in the whole basin increases in future from a value of 13.5 Mm^3 to 16.4 Mm^3.

The result from the Water Balance Analysis indicates that there is potential to cover to a large extent the water demands by the year 2030 if a set of recommended interventions are applied (Erection of three dams, improving, existing hydraulic infrastructure, rehabilitation of Hafirs at downstream side, and use the Turda as storage dam). The study ranked these alternative options in descending order as Haffir, Tarda, Tagor dam, Kajeer dam and UmTagerger dam. However, a tight control of the growth of the future demands will be needed, although this may be difficult in a rapidly growing developing community. To conclude the study ended by a set of recommendations for policy making and for future research.

المستخلص

أن القدرة على تقييم القدرة الهيدرولوجية لمياه خور أبو حبل لتلبية الطلب على المياه المستقبلية أمر بالغ الأهمية للخطط المستقبلية واتخاذ قرارات حكيمة. في هذه الدراسة تم استخدام طريقة تحليل السيناريو باستخدام نموذج حوض النيل لدعم اتخاذ القرار لإدارة الموارد المائية وتقييم توزيعها وتخطيطها لاغراض تقييم التأثيرات المستقبلية المحتملة على طلب المياه في جابية خور أبو حبل. في كل سيناريو تم تحليل النتائج الرئيسية للنموذج لقطاعات المياه المختلفة، وللمستخدمين و لتيارالمياة الجاري حتى مخرج خور ابو حبل والمياه الممكن تخزينها في الخزانات.

تم تطبيق نموذج حوض النيل لدعم اتخاذ القرار بنجاح في حوض أبو حبل واحواضه الفرعية. هذا بالاضافة الى انه قد تم استخدام بيانات الأقمار الصناعية للحصول على (أ) الممارسات الزراعية الحالية (ب) الأراضي الصالحة المتاحة للزراعة والاستخدام المدني (المناطق الحضرية والريفية) والتضاريس، واستخدام الأراضي وغيرها من المتغيرات و (ج)المناخ من الاقمار الصناعية.

تم استخدام نظام حوض النيل لدعم اتخاذ القرار إلى تزيد صانعي القرار بمنصة حاسوبية عملية و لتقييم خيارات إدارة المياه والخطط الاستراتيجية الإقليمية. ويضم نظام حوض النيل لدعم اتخاذ القرار وحدة لإدارة المعلومات الذي يقوم بالجمع والتحقق والإدارة والتصور للبيانات والمخرجات من نماذج تقدر الطلب للمحاصيل للمستويات مختلفة من وحدات استخدام المياه. تم محاكاة توزيع المياه بين الاستخدامات المختلفة لفترة زمنية طويلة باستخدام نموذج قطعي التي تعمل على خطوة زمنية شهرية (لعام 2030).

و تم استخدم طريقة التقييم الخاصة بنظام حوض النيل لدعم اتخاذ القرار لمقارنة آثار خمسة خيارات استراتيجية للتدخل للهياكل التحتية (بناء حفاير، ثلاثة سدود، توردا السد) على أساس واضح المعالم، شامل ست ومؤشرات باستخدام منهج المعايير متعددة وذلك بالتعبير عن الثلاثة مبادئ الرئيسية للإدارة المتكاملة للموارد المائية بما في ذلك: توافر المياه (الامداد)، وتحسين إنتاجية المحاصيل والاقتصاديات (تكاليف التطوير)، والأثر ومخاطر على المستخدمين في المصب، والاستدامة البيئية.

الهدف من هذه الدراسة هو المساعدة في عملية اتخاذ القرارات المتعلقة بتقييم سيناريوهات إدارة المياه والخطط وتنفيذ خيارات التدخل في الوقت الحقيقي لمواجهة التغيرات في إمدادات المياه مما يسمح ببناء للتطورات المستقبلية للموارد المائية في الجابية تكون مبنية على اساس العلاقة بين العرض والطلب على المياه. تم اختبار النظام لتوزيع حصص المياه إلى مستويات استخدام مختلفة لتكوناساس قياسي وكأداة مبنية على المياه الفعلية المتاحة والقائمة (سنة الأساس 2012) و المتوقعة للحالات المستقبلية (عام 2030)

اوضحة نتائج والتحليل النموذج أن: الجريان السطحي إذا تمت إدارته بكفاءة كافيا لتغطية الطلب المتزايد على المياه التي تتراوح بين 44361.88 مليون م^3 في السيناريو سنة الاساس و55036.02 مليون م^3 في سنة 2030.

تم تسجيل نقص كبير في أم تقرقر حيث يصل العجز المائي السنوي 10.7 مليون م^3 / سنة لظروف الحالية (2012) ويتزايد النقص الى 12.9 مليون م^3 / سنة في سيناريوهات مستقبلية (2030). وياتي بعدة خور كجير والنقص فية حاليا 2.6 مليون م^3 والذي سيرتفع في المستقبل إلى 3.0 مليون م^3 العجز المائي في الحوض كله سيزداد في المستقبل من قيمة 13.5 مليون م^3 إلى 16.4 مليون م^3.

النتيجة من تحليل الموازنة المائية تشير إلى أن هناك إمكانية لتغطية الطلب على المياه لحد كبير بحلول عام 2030 إذا تم تطبيق مجموعة من التدخلات الموصى بها (تركيب ثلاثة سدود، وتحسين البنية التحتية المائية الحالية، وإعادة تأهيل الحفاير في جانب المصب ، واستخدام التوردا كسد تخزين). صنفت هذه الخيارات البديلة في ترتيب تنازلي هو الحفاير، التردة ، سد تقور، سد كجير و سد أم تقرقر. ومع ذلك، سوف تكون هناك حاجة لرقابة مشددة غلى نمو الطلب في المستقبل، على الرغم من أن هذا قد يكون من الصعبا في المجتمع النامي نموا سريعا. وفي الختام انتهت الدراسة بمجموعة من التوصيات لوضع حزمة من السياسات للظروف الحالية وللبحث في المستقبل.

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ABBREVIATIONS

Particular	Description
ARMA	Autoregressive–moving-average
CGWB	Central Ground Water Board
CSV	Comma Separated Value
CWC	Central Water Commission
DEM	Digital Elevation Model
DIU	Dams Implementation Unit
DSF	Decision Support Framework
DSS	Decision Support System
EPA	Entry Point Activity
ESRI	Environmental Systems Research Institute
ETo	Evapotranspiration
FAO	United Nations Food and Agricultural Organization
Fed	Fadden
GIS	Geographic Information System
GS	Grid Station
ha	Hectare
ICID	International Commission on Irrigation and Drainage.
IFAD	International Fund for Agricultural Development

IMD	Indian Metrological Department
IMS	Information Management System
ISRO	Indian Space Research Organization
IT	Information Technology
IWRM	Integrated Water Resource Management
Km	Kilometer
Km2	Square kilometers
l/p/d	liters/person/day
m3/s	cubic meters per second
M	Meter
MCM	Million Cubic Meters
Msl	Mean Above Sea Level
MRC	Mekong River Commission
MCA	Multi-Criteria Analysis Tools
NAM	Nedbörs Afströmnings Model (Danish for run-off model)
NB	Nile Basin
NBI	Nile Basin Initiative
NDVI	Normalized Difference Vegetation Index
NRSC	National Remote Sensing Centre
PMU	Project Management Unit
RBM	River Basin Modeling System

SAP	Strategic Action Program
SRTM	Shuttle Radar Topography Mission
TRMM	Tropical Rainfall Measuring Mission
TSedit	Time Series Edit tool
USGS	United State Geological Survey
UHM	Unit Hydrograph Module
WRD	Water Resources Department
WMS	Water management Scheme
WMO	World Meteorological Organization

CHAPTER ONE

1. INTRODUCTION

1.1 Background and Justification

Water shortage in many parts of the world frequently occurs because of global climate change and the increasing intensity of human activity. The main reason for water crises is the lack of sustainable methods of water resource management (UNESCO, 2006). Water resource management, however, is increasingly influenced by climate change and human activities (Arnell, 1998; Christensen and Lettenmaier, 2007). Climate change is an exogenous process related to runoff and precipitation, which cannot be easily affected by decision makers, managers or farmers. Climate change can cause more extreme hydrological events (e.g., flood, drought) and create greater uncertainty in water resource management. The impacts of human activities (e.g., hydraulic engineering, crop structure, and water allocation among multi-level sectors) on water resource management are subjective and can be easily prioritized by policy makers based on the information available to them. It may be difficult for decision makers or managers to devise a water allocation scheme for a particular region within a particular period without up-to-date information due to the considerable extent of human activities.

The decision-making processes associated with the utilization of water resources are very complex, and require thorough consideration and analysis. Sectorial approaches to water resources development and management have been and still are dominant (Lilburne et al., 1998; Salman et al., 2001) but there is need for a shift towards a holistic approach to avoid fragmented and uncoordinated policies (Staudenrausch and Flugel, 2001). Additional challenges arise in the field of water policy from the multi-dimensional interactions between the various aspects of human activities, their impact on natural systems and the corresponding influence of natural responses upon the human domain (Simon et al. 2004).

Water resources systems are complex ones that encompass different interlinked components, including technical, economic, social, cultural, environmental and legal aspects. A river basin system, for example, can include several ecosystems with different hydrological sub-systems, various kinds of water uses supporting different social and economic activities, different types of actors with different interests related to water and numerous types of 'institutions' – sets of rules, regulations and policies – regarding water allocations.

Increasing pressure on water resources has, in many instances, resulted in, amongst other things, a lack of safe and affordable drinking water and basic sanitation, inadequate water resources for economic sectors such as agriculture and energy and transboundary conflicts over allocation. Such aspects have created public pressure, followed by government responses in terms of an increased focus on rational water resources management, planning and development. The search for efficient and effective approaches has led to the development of IWRM, which has been applied globally for the last 20 years.

This study, therefore, investigate the management strategic options to improve water availability and introduces a methodology for allocating water based on water requirements and equity to help multi-level decision makers manage water resources in a DSS while fully accounting for the effects of human activities (e.g., hydraulic engineering and crop structure). The methodology is achieved via utilizing NB- DSS for water allocation along Khor Abu Habil various reaches in southern parts of North Kordofan State of Sudan. This NB-DSS integrates GIS, Internet, relational database (SQLServer), software engineering, and visualization techniques to provide a flexible, user-friendly, and applicable information system. The NB-DSS also incorporates models that are used to calculate the components related to solving water resource management problems.

The next section introduces a brief background description of the water resource management context in Khor Abu Habil basin. As such, this dissertation evaluates the water management and planning challenges in the rural river basins of the developing world in general and in Khor Abu Habil of Sudan in particular, where demands are growing and the supply is limited. While many of these basins have yet to reach the state of closure, their water users are already experiencing water shortages. Agricultural crop production in Khor Abu Habil basins of the Southern parts of the State of North Kordofan plays a major role in ensuring food security. However, irrigation as the major water consumer in the basins has low water use efficiency. As water scarcity grows, the need to maximize economic gains by reallocating water to more efficient uses becomes important. Water planning decisions must be made considering the hydrological, social economic and environmental conditions of the basin. The purpose of this dissertation is to identify water management strategies that satisfy the above conditions, in the case study of the Khor Abu Habil basin.

1.2 Problem Definition

In the last century, water use has increased at greater than twice the rate of the population growth. By 2025, 1.8 billion people are expected to live in countries or regions with absolute water scarcity, and two-thirds of the world's population could be under conditions of water stress (FAO, 2007). Agriculture is the predominant consumer of water in most countries, accounting for more than 70 percent of global water use and up to 95 percent in many developing countries. Improved agricultural water management is required to realize global environmental and social goals with respect to poverty, hunger, and sustainable environment and to mitigate many water-related issues (Molden, 2007).

A clear understanding of the hydrologic components controlling water balance is essential to analyze possible measures for saving water in a watershed with agricultural reservoirs for improved water-resource planning and management. However, many of the components are not easily measurable either in terms of the required time interval or the complexity of the processes in a river-basin system where agriculture is a dominant land use (Droogers, et al, 2000). Compared to field monitoring, use of simulation models is a relatively inexpensive and quick method to investigate the rainfall-runoff process in developing water resources management plans. Further, highly nonlinear, time varying, and spatially heterogeneous hydrologic processes can be effectively represented in modeling by employing appropriate models (Bevenand ; Freer , 2001; Douglas-Mankin, et al , 2010;Her and Heatwole, 2016). Numerous studies have exploited the usage of modeling approaches in watershed management planning, and a range of models and software has been developed for their specific purposes and uses.

For decades, modular-style software development has been a trend in software engineering

The development and management of ephemeral catchments (Khors and Wadis) in Sudan require detailed water management frameworks that promote equitable, integrated and sustainable management of the water resources. The ephemeral rivers of Sudan (Wadis and Khors) are flowing only for few weeks or months every year, and they are often flashy with a sudden rise of the water flow and difficulties in both capturing and monitoring these floods. The benefits of water harvesting of the flood waters are high in such areas; in domestic use as well as irrigated agriculture. There is, hence, a need for formulation of Integrated Water Resources Management (IWRM) plans, which define carefully selected development scenarios that assure the supply of water for key water uses.

Catchment specific IWRM plans constitute detailed guiding documents, which are based on the local context and area specific opportunities and challenges.

The use of analytical modeling tools in integrated water resources management (IWRM) provides important instruments both for finding the best water use solutions and achieving water security for multiple purposes in a sustainable and equitable manner. It also facilitates the management and mitigation of extreme climate events. Water security requires resolving trade-offs to maintain a proper balance between meeting various sectors' needs and taking into account present and future overall social, economic and environmental goals.

1.3 Study Objectives

The objectives of this study are four folds:

(a) To find out the available water resources at Abu Habil basins and sub-basin scale system.

(b) To develop a basin-wide analytical water resources assessment using NB-DSS for determining rational and effective water management scenarios at the river basin scale for the current and future situations.

(c) To define a set of improvement interventions and plans and implementation. These options to aid real-time responses to changes in water supply, allowing future developments and improvement in utilization of watershed water resources to be based on the actual relationship between the supply and demand for water.

(d) To develop scenarios using NB-DSS Multi criteria analytical module for evaluating both the expected management scenarios and the set of development improvement interventions

1.4 Study Scope

- **Chapter 1** is the introductory part of the research work.
- **Chapter 2** is the review of literatures related to integrated water resources management and DSS at basin/sub basin level.
- **Chapter 3** gives the outline of study area Abu Habil river basin, topographic features, precipitation, soil characteristics, land use, land cover pattern and various data collected for NB-

DSS model set up. The chapter illustrates the methodology, a detailed step by step procedure of NB-DSS model working principles for all sectors, viz Agriculture, Domestic, Industries and Environmental flows.

- **Chapter 4** describes the results of NB-DSS model outputs.
- **Chapter 5** represents the concluding section of research work, and the scope of future work.
- The Thesis end is the list of references.

CHAPTER TWO
2. LITERATURE REVIEW

2.1 Integrated Water Resources Management (IWRM):

There is growing awareness that comprehensive water resources management is needed, because:

- fresh water resources are limited;
- those limited fresh water resources are becoming more and more polluted, rendering them unfit for human consumption and also unfit to sustain the ecosystem;
- those limited fresh water resources have to be divided amongst the competing needs and demands in a society
- many citizens do not as yet have access to sufficient and safe fresh water resources
- techniques used to control water (such as dams and dikes) may often have undesirable consequences on the environment
- There is an intimate relationship between groundwater and surface water, between coastal water and fresh water, etc. Regulating one system and not the others may not achieve the desired results.

Hence, engineering, economic, social, ecological and legal aspects need to be considered, as well as quantitative and qualitative aspects, and supply and demand. Moreover, also the 'management cycle' (planning, monitoring, operation & maintenance, etc.) needs to be consistent. Integrated water resources management, then, seeks to manage the water resources in a comprehensive and holistic way. It therefore has to consider the water resources from a number of different perspectives or dimensions. Once these various dimensions have been considered, appropriate decisions and arrangements can be made.

Due to the nature of water, integrated water resources management has to take account of the following four dimensions:

1. The *water resources*, taking the entire hydrological cycle in account, including stock and flows, as well as water quantity and water quality; distinguishing for instance white, green, grey and blue water

2. The *water users*, all sector interests and stakeholders

3. The *spatial scale*, including

a. The spatial distribution of water resources and uses

b. The various spatial scales at which water is being managed, i.e. individual user, user groups (e.g. user boards), watershed, catchment, (international) basin; and the institutional arrangements that exist at these various scales

4. The *temporal scale*; taking into account the temporal variation in availability of and demand for water resources, but also the physical structures that have been built to even out fluctuations and to better match the supply with demand.

Considering this background Integrated Water Resources Management (IWRM) can now be defined as: the process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems.

This is the definition proposed by the Global Water Partnership:

Integrated Water Resources Management therefore acknowledges the entire water cycle with all its natural aspects, as well as the interests of the water users in the different sectors of a society (or an entire region). Decision-making would involve the integration of the different objectives where possible, and a trade-off or priority-setting between these objectives where necessary, by carefully weighing these in an informed and transparent manner, according to societal objectives and constraints. Special care should be taken to consider spatial scales, in terms of geographical variation in water availability and the possible upstream-downstream interactions, as well as time scales, such as the natural seasonal, annual and long-term fluctuations in water availability, and the implications of developments now for future generations.

To accomplish the integrated management of water resources, appropriate legal, institutional and financial arrangements are required that acknowledge the four dimension of IWRM. In order for a society to get the right arrangements in place, it requires a sound policy on water (van der Zaag,2003).

2.2 Aspects of Decision Support System (DSS)

The DSS uses the concept of a water management scheme (WMS), defined as a set of scenarios for variables that cannot be directly influenced by the decision maker (i.e. rainfall patterns constituting a water availability scenario and population growth formulating a demand scenario) and the application of one or more water management interventions.

A WMS is defined in terms of a database containing information on the water infrastructure at a certain region and reference year, at which the implementation of scenarios and strategies begins. A base case is always present, serving as input for the creation of new WMSs. User interaction with the DSS falls under three functional groups, accessed via a hierarchical navigation tree: (a) base case editing, allowing for the editing and introduction of new data for the reference year; (b) creation of WMSs, providing the capabilities for defining scenarios on water availability and demand, definition of strategies and visualization of results and for conducting a parametric economic analysis, and; (c) evaluation, which permits the comparison of different WMSs according to a predefined set of indicators.(Fig.1).

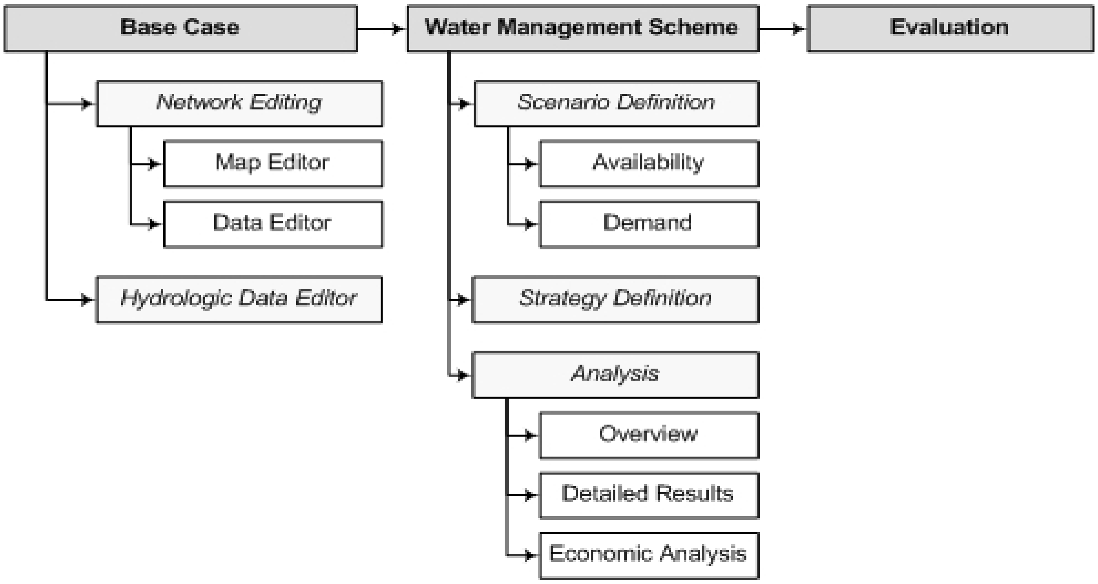

Figure 2.1: The DSS operational framework (After Manoli et al 2001)

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The Demand Scenarios Module produces forecasted time-series of water demand for all water uses, generated by specifying appropriate growth rates to the key variables (Drivers) that govern demand pressures, such as population for domestic use, cultivable area and livestock for agricultural practices, production growth for industries and minimum required energy production from hydropower plants.

Application of water management instruments can be performed either through proper customization of abstract actions, or through modification of the properties of network objects and the introduction of new ones. As an example, supply regulation through quotas can be performed through application of the respective action, where the user defines the maximum volume of demand that can be met under a specified time period, and the geographic area of application.

DSS modeling frameworks: An open modeling interface will allow a generic DSS framework to access and apply mathematical models from different suppliers within the DSS for the management purposes required, e.g. general water resources management, flood management, climate change analysis, etc. An open interface to model codes requires so-called adapters, which enable the DSS to access prepared input data and model parameters, and store relevant model results. The benefits of an open architecture and adapters are that the DSS is not tied to a particular vendor and, moreover, that new tools developed in the future can be plugged into the DSS. Often model codes have already been developed, accepted and applied by a water authority, and instead of replacing them with new model codes, the creation of adapters to existing codes ensures that the work already invested in existing model codes is not wasted. Hence, configuration of a DSS framework acts as an umbrella for a series of model codes and other tools.

The *Analysis* branch provides the visualization of results from the simulation of each water management scheme, through three functions. The *Overview* displays yearly aggregated results on water demand and shortage for the main sectors, freshwater abstractions, and costs (direct and environmental) as well as benefits from water use.

The *Detailed Results* section provides the results of the allocation in terms of appropriately customized indicators aggregated either for the entire region or presented for each type of network object. Finally, the *Economic Analysis* branch permits the selection of appropriate models and parameters for the estimation of direct, environmental and resource costs and the definition of benefits from water uses, avoiding repetition of the entire simulation procedure (Manoli et al 2001).

DSS Structure: The structure is divided into three parts:

(1) Geographic Information System for the visualization through GIS maps;

(2) Model Base System, which includes simulation and optimization models (e.g. for irrigation design and management), evaluation criteria and scenario techniques;

(3) Database System to manage the data within the DSS. (Billibi et al, 2007)

2.2.1 DSS Elements

Decision Support Systems (DSS) are technical tools intended to provide valid and sufficient information to IWRM decision makers. A typical DSS for IWRM includes five main components: data acquisition system, user-data-model interface, database, data analysis tools, and a set of interlinked models.

The data acquisition system consists of all means by which generic data are collected and made available to IWRM through the DSS. Data may be collected by conventional sensors (rain gages, stream-gages, etc.), remote sensors (satellite, radar), as well as by manual compilation efforts (e.g., surveys, interviews, and literature reviews). The purpose of the user data- model interfaces to (1) transfer the data to the database, and (2) provide easy and meaningful access to data, data analysis tools, and application programs (models).

The database is the depository of all data acquired by the data acquisition system and generated by the data analysis tools and application programs.

The data analysis tools provide user-friendly means to visualize and analyze various data sets.

Geographic Information Systems (GIS) packages are especially important for the visualization and analysis of geo-referenced (spatial) data. Lastly and most importantly, the purpose of the DSS models is to quantify the holistic response of the water resources system to alternative scenarios of basin development, hydrology, water use levels, and management policies. (Aris P. Georgakakos, 2004)

Applications: Over time, the applications of DSS and of hydro-economic modeling have demonstrated their strength in assisting decision-level staff to address issues relating to IWRM. Seven notable examples/cases are described briefly in Global Water Partnership, 2013, and they include:

Mekong River Commission (MRC) – Decision Support Framework (DSF)
Development and Deployment of the Nile Basin DSS
Hydro-economic modeling in the Euphrates-Tigris Region
The Zambezi River Basin Multi-sector Investment Opportunities Analysis
The Application of Hydro-economic modeling in the Rio Grande Basin
The Okavango River Basin DSS
National Institute of Hydrology, India, 'DSS Planning' for IWRM

2.2.2 *Development and Deployment of the Nile Basin Decision Support System (NB-DSS)*

Rationale: The riparian countries of the Nile – Burundi, Democratic Republic of Congo, Egypt, Ethiopia, Kenya, Rwanda, Sudan, Tanzania and Uganda – have embarked on the Nile Basin Initiative (NBI). The NBI is governed by the Council of Ministers of Water Affairs of the Nile Basin States and seeks to develop the River Nile in a cooperative manner, sharing socioeconomic benefits and promoting regional peace and security. Their shared vision is to "achieve sustainable socioeconomic development through the equitable utilization of, and benefit from, the common Nile Basin water resources." A Strategic Action Program (SAP) should translate this vision into concrete activities and projects. An important part of the shared vision is the establishment of shared and accepted water management tools and technologies. For this purpose the Nile Basin DSS was developed.

DSS (NB DSS), funded mainly by the World Bank through the Nile Basin Trust Fund, with the aim of supporting international policies at strategic level, and trans-boundary planning and management and which includes an information management system and a river basin model connected to a graphical user interface and communication system and supported by a toolkit of analytical tools .

Description: The NB DSS design is based on three major functional components, namely, the Information Management System (IMS), the River Basin Modeling System (RBM), and the Multi-Criteria Analysis Tools (MCA). The development of the Nile Basin DSS contains two separate work packages. Work package 1 is essentially an information technology (IT) project focusing on the development of the Nile Basin DSS while Work package 2 is designed for independent system testing and pilot application. Key activities were elaboration of the Nile Basin DSS software requirements, software architecture and design, software development and testing, training of local staff and system deployment in the nine countries. The Nile Basin DSS software requirements are rooted in 'use cases' developed by the NBI and further elaborated during the course of the project. The Nile Basin DSS is designed to support water resources planning and investment decisions in the Nile Basin, especially those with cross-border or basin level ramifications. The system consists of an IMS linked with river basin modeling systems and a suite of analytical tools to support a multi-objective analysis of investment alternatives.

The Nile Basin DSS will aid in the development of core national capabilities, in the evaluation of alternative development paths and in the identification of joint investment projects at sub-regional and regional levels. The NBI has established a small, strong project management unit (PMU) staffed by DSS specialists and IT and modeling experts. In addition, IT and water resources modeling experts from all nine countries have participated in all project phases, ranging from elaboration of requirements to system testing.

Two interim Nile Basin DSS releases have been successfully deployed, tested and accepted by the NBI. The final Nile Basin DSS was deployed in all countries in September 2012. A service agreement is in place ensuring that the NBI will have access to support and software updates. The training and involvement of local staff have been key.

At this stage, more than 50 Nile Basin water professionals have been trained by DHI. Moreover, the NBI PMU has invested substantial resources in involving additional engineers and managers through training sessions and workshops in the NBI countries. Through such training sessions a very large number of local staff have been trained or exposed to the Nile Basin DSS even before its final release.

Lessons learned: The lessons learned can be summarized in:

_ Substantial training and client involvement during the project has created a very strong feeling of ownership at the NBI

_ Software requirements should be based on, or supported by, 'use cases' developed by CASE TITLE: Hydro-economic modeling in the Euphrates-Tigris Region the client. This process to ensure and demonstrate the ability of the system to address real-life problems and key issues in relation to client involvement and ownership is time consuming, but important

_ To sustain and further enrich the Nile Basin DSS a post-project plan must be put in place, including staffing, institutional setup and funding.

Replicability: The NBI has chosen to base the Nile Basin DSS on DHI's MIKE Customized software platform.

The NBI has contributed significantly to the development of the platform. The software platform will now be maintained and further developed by DHI and will be used to serve many other systems throughout the world.

The NB DSS is evidently a very ambitious initiative, which, according to Dr. Seid is facing the common problems related to the quality of available data (in the Nile Basin hydro-meteorological data is scarce and often of poor quality), and also the challenge of uncertainty of future sustainability and the required efforts to ensure the required financial and institutional support. Relevant for future sustainability is the long term perspective (beyond 2018) of using the NB DSS as a tool for the Water Resources Management Unit (WRMU) at the NBI-Secretariat to become a provider of services to other entities and projects thereby and thus having perspectives for becoming financially self-sufficient.

According to Seid (2013) the main strengths of the NB DSS are its flexibility, strengths as assets for long term sustainability and capacity to deal with different temporal and spatial scales (e.g. national and transnational).

2.3 Watershed Management

2.3.1 Definition of Watershed:

A watershed, also called a drainage basin or catchment area, is defined as an area in which all water owing into it goes to a common outlet. People and livestock are the integral part of watershed and their activities affect the productive status of watersheds and vice versa. From the hydrological point of view, the different phases of hydrological cycle in a watershed are dependent on the various natural features and human activities.

Watershed is not simply the hydrological unit but also socio- political-ecological entity which plays crucial role in determining food, social, and economical security and provides life support services to rural people (Wani , et al.2008).

2.3.2 Delineation of Watershed:

From Hydrological view, watershed is an area from which the runoff flows to a common point on the drainage system. Every stream, tributary, or river has an associated watershed, and small watersheds aggregate together to become larger watersheds.

Water travels from headwater to the downward location and meets with similar strength of stream, and then it forms one order higher stream. The stream order is a measure of the degree of stream branching within a watershed.

Each length of stream is indicated by its order (for example, first-order, second- order, etc.). The start or headwaters of a stream, with no other streams flowing into it, is called the first-order stream. First-order streams flow together to form a second-order stream. Second-order streams flow into a third-order stream and so on. Stream order describes the relative location of the reach in the watershed.

Identifying stream order is useful to understand amount of water availability in reach and its quality; and also used as criteria to divide larger watershed into smaller unit. Moreover, criteria for selecting watershed size also depend on the objectives of the development and terrain slope. A large watershed can be managed in plain valley areas or where forest or pasture development is the main objective (Singh, 2000). In hilly areas or where intensive agriculture development is planned, the size of watershed relatively preferred is small.

2.3.3 Components of Watershed Management

a. Entry Point Activity (EPA): Entry Point Activity is the first formal project intervention which is undertaken after the transect walk, selection and finalization of the watershed. It is highly recommended to use knowledge-based entry point activity to build the rapport with the community. Direct cash-based EPA must be avoided as such activities give a wrong signal to the community at the beginning for various interventions. Details of the knowledge-based EPA to build rapport with the community ensuring tangible economic benefits to the community members are described here.

b. Land and Water Conservation Practices: Soil and water conservation practices are the primary step of watershed management program. Conservation practices can be divided into two main categories: 1) *in-situ* and 2) *ex-situ* management. Land and water conservation practices, those made within agricultural fields like construction of contour bunds, graded bunds, field bunds, terraces building, broad bed and furrow practice and other soil-moisture conservation practices, are known as in-situ management .These practices protect land degradation, improve soil health, and increase soil-moisture availability and groundwater recharge. Moreover, construction of check dam farm pond, gully control structures, pits excavation across the stream channel is known as *ex-situ* management. *Ex-situ* watershed management practices reduce peak discharge in order to reclaim gully formation and harvest substantial amount of runoff, which increases groundwater recharge and irrigation potential in watersheds.

2.3.4 Watershed Management Approaches

A. Integrated Approach: This approach suggest the integration of technologies within the natural boundaries of a drainage area for optimum development of land, water, and plant resources to meet the basic needs of people and animals in a sustainable manner. This approach aims to improve the standard of living of common people by increasing his earning capacity by offering all facilities required for optimum production (Singh, 2000). In order to achieve its objective, integrated watershed management suggests to adopt land and water conservation practices, water harvesting in ponds and recharging of groundwater for increasing water resources potential and stress on crop diversification, use of improved variety of seeds, integrated nutrient management and integrated pest management practices, etc.

Consortium Approach: Consortium approach emphasizes on collective action and community participation including of primary stakeholders, government and non-government organizations, and other institutions. Watershed management requires multidisciplinary skills and competencies. Easy access and timely advice to farmers are important drivers for the observed impressive impacts in the watershed. These lead to enhance awareness of the farmers and their ability to consult with the right people when problems arise. It requires multidisciplinary proficiency in field of engineering, agronomy, forestry, horticulture, animal husbandry, entomology, social science, economics and marketing. It is not always possible to get all the required support and skills-set in one organization. Thus, consortium approach brings together the expertise of different areas to expand the effectiveness of the various watershed initiatives and interventions (Suhas and Kaushal, 2000).

2.4 Water Resources in Sudan

Sudan is rich in water (from the Nile system, rainfall and groundwater) and lands resources (Table 2.1).Surface water resources are estimated at 84 billion m3 and the annual rainfall varies from almost nil in the arid hot north to more than 1600 mm in the tropical zone of the south

Table (2.1): Land use, land-resource zones and water resources

(a) Land use	(millions of ha)
Geographical area (total Sudan area)	250.6
Land area	237.6
Cultivable area	8.4
Pastures	29.9
Forests and woodland	108.3
Uncultivable land	81.0
Area under crop (irrigated, rain-fed, mechanized, and rain-fed traditional	10.0

<table>
<tr><th colspan="4">(b) Land-resource zones</th></tr>
<tr><td>Zone</td><td>Area as % to total area of Sudan</td><td>Persons per km2</td><td>Mean average rainfall range (mm)</td></tr>
<tr><td>Desert</td><td>44</td><td>2</td><td>0-200</td></tr>
<tr><td>QOS sands</td><td>10</td><td>11</td><td>200-800</td></tr>
<tr><td>Central clay plains</td><td>14</td><td>19</td><td>200-800</td></tr>
<tr><td>Southern clay plains</td><td>12</td><td>8</td><td>800-900</td></tr>
<tr><td>Ironstone plateau</td><td>12</td><td>7</td><td>800-1400</td></tr>
<tr><td>Hill area and others</td><td>8</td><td>16</td><td>Variable</td></tr>
<tr><td colspan="4">(c) Water resources</td></tr>
<tr><td></td><td>Available number</td><td>Static water level (m)</td><td>Number</td></tr>
<tr><td>Haffirs</td><td>824</td><td>0-0</td><td>824</td></tr>
<tr><td>Slow sand filters</td><td>128</td><td>0-0</td><td>128</td></tr>
<tr><td>Open shallow wells</td><td>3000</td><td>0-10</td><td>3000</td></tr>
<tr><td></td><td></td><td>0-25</td><td>1248</td></tr>
<tr><td></td><td></td><td>26-50</td><td>478</td></tr>
<tr><td>Boreholes deep wells</td><td>2259</td><td>51-7</td><td>287</td></tr>
<tr><td></td><td></td><td>76-100</td><td>246</td></tr>
</table>

(d) Geological Formations					
Basins	Amount of water recharged (106 m3)	Water level below land (m)	Aquifer thickness (m)	Velocity (m/year)	Abstraction (106 m3/year)
Sahara Nile	136	30-100	300-500	1-2.5	7.3
Sahara Nubian	20.6	Oct-50	300-500	0.8-1.5	1.5
Central Darfur	47.6	25-100	250-550	0.3-6	5.5
Nuhui	15.4	75-120	200-400	1-2.75	1.6
Sag El Na’am	13.5	50-1000	300-500	25-Jan	2.5
River Atbara	150	100-150	250-300	0.3-5	2.3
Sudd	341	25-Oct	200-400	0.1-1.8	1.8
Western Kordofan	15	50-70	300-500	0.1-0.3	1.7
Baggara	155	Oct-75	300-500	0.1-2.4	11.9
Blue Nile	70	Oct-50	250-500	0.1-2.5	10.2
The Alluvial	N.A	Shallow	N.A	N.A	N.A
Gedaref	41.7	50-75	200-500	0.1-2	1.2
Shagara	1.1	25-30	200-300	0.1-2.5	0.7

Source: Omer 2002 –Data for old Sudan before separation

The total quantity of groundwater is estimated to be 260 billion m3, but only 1% of this amount is being utilized.

Water-resources assessment in Sudan is not an easy task because of uncertainty of parameters, numerous degrees of freedom of variables, lack of information and inaccurate measurements. However, according to seasonal water availability, Sudan could be globally divided into three zones: (a) Areas with water availability throughout the year are the rainy regions (equatorial tropical zones); (b) Areas with seasonal water availability, and (c) areas with water deficit throughout the year, which occupy more than half the area of Sudan (Omer , 2010).

2.5 Spate Irrigation

2.5.1 Definitions, classification and concepts

Spate irrigation is a unique form of water resource management that has been practiced in arid and semi-arid regions where evapotranspiration greatly exceeds rainfall. UNDP and FAO (1987) defined spate irrigation as “an ancient irrigation practice that involves the diversion of flashy spate floods running off from mountainous catchments where flood flows, usually flowing for only a few hours with appreciable discharges and with recession flows lasting for only one to a few days, are channeled through short steep canals to bounded basins, which are flooded to a certain depth”. Subsistence crops, often sorghum, are typically planted only after irrigation has occurred. Crops are grown from one or more irrigations using residual moisture stored in the deep alluvial soils formed from the sediments deposited in previous irrigations.

A simpler definition of spate irrigation was given by Mehari et al. (2007) as “a resource system, whereby flood water is emitted through normally dry Wadis and conveyed to irrigable fields”.

Distinguishes floodwater harvesting within streambeds, where channel flow is collected and spread through the Wadi where the crops are planted, from floodwater diversion, where the floods – or spates – from the seasonal rivers are diverted into adjacent embanked fields for direct application. In all these cases, spate irrigation is characterized by the arid environment in which it takes place, the unpredictable nature of flood water to be harnessed, high sediment loads and a complex social organization.

There are several variants of spate irrigation and several terms are used to describe similar practices. Spate irrigation has some similarities with flood inundation and flood recession systems found along alluvial plains, where crops are grown from the residual moisture following floods. The term water harvesting is also used to describe the practice in which the flow discharged from a small catchment area after a storm is directed through channels to a nearby field enclosed by bunds, and soil moisture is increased by subsequent infiltration, while runoff farming usually refers to in situ collection of rainwater in the field to increase moisture in the root zone. In all cases, the crops take up the supply of water in the soil during the dry periods that follow rainfall and they can survive longer periods without yield losses in places with deeper and heavier soils (Tauer and Humborg, 1992).

There are two important features that distinguish spate irrigation from these other forms of flood irrigation. The first is that, in spate irrigation, flood water is physically diverted from wadi channels via canals to bounded fields that may be located at some distance from the water course. The second is that spate irrigation is carried out on a large scale, by groups of farmers rather than individuals, who need to work closely together to divert and distribute flood waters and maintain their intakes and canals. Spate irrigation is also distinct from semi-perennial irrigation, as it depends on short duration floods, whereas semi-perennial irrigation makes use of flows lasting weeks, even months. In all cases, however, the dividing line is thin.

According to van Steenbergen, et al, (2010) the common features of most spate irrigation schemes are:

_Ingenious diversion systems built to capture short floods but also designed to keep out the larger and most destructive water flows.

_ Sediment management, as the flood water has high sediment loads that would otherwise fill reservoirs and clog intake structures and distribution canals; these sediments are used to build up soil and level the land but can also result in excessive rising of land and loss of command.

_ the importance of soil moisture conservation, especially as floods often come ahead of the sowing season.

_ a sophisticated social organization to manage the sometimes complex system, ensure timely maintenance of the structures and channels and oversee the fair distribution of the flood water, even though it comes in unknown quantities at unpredictable times.

2.5.2 Administration of spate irrigation:

In the case of spate irrigation, water conflict arises usually between the upstream irrigators and low stream irrigators. According to Kiflemariam (2001), the water supplied by spate irrigation is unstable and erratic. The hallmark of spate irrigation is change; there is change in the size and frequency of floods, a change in cropped areas and crop productivity, and even a change in the land configuration itself due to different interacting factors. Water is delivered on a field-to-field basis. As the flood arrives first in the lower point of the irrigation river, the topmost fields get water before the next field. In other words, if the fields located further from the irrigation river, are to get water, first the topmost fields have to get sufficient water. After filled with sufficient water, one of the topmost field bunds is breached and water is allowed to flow across the top field to fill the next field in an ordered succession of fields. Thus, it is difficult to ensure equity in the distribution of water in spate irrigation in the Project area. As there are no permanent structures to control the floods, during periods of heavy floods the topmost fields get washed away, and during periods of little floods only the topmost fields get water and the far-located fields do not get any. There are some ways of regularizing distributions closely linked with the location of the field and size of the flood. It is advantageous for upstream farmers to construct low-level field embankments to contain series of minor floods. If they, however, construct high- level field embankments, larger floods easily destroy the upstream field embankments requiring the farmers to construct them again. It is advantageous for lower stream farmers to construct high-level field embankments because the force of large floods has been progressively dissipated and the danger of destruction is less while its water conserving capacity is high.

2.5.3 Spate Irrigation in Sudan:

General: Spate irrigation with its total area of 285,000 ha is an important contributor to poverty alleviation and improvement of rural livelihood of the population in the most marginal areas of the country. During the time of the British colonial administration some very large spate irrigation systems were developed – in particular the Gash and the Tokar systems. Both of these systems are supplied by major rivers originating from Eritrea – respectively the Gash and the Baraka and both ultimately disappear in inland delta. The Gash and Tokar systems were originally developed for cotton export – but over the years the economic environment has drastically changed. Other spate irrigation areas in Sudan are Khor Abu Habil in Kordofan and

Derudeb in the Port Sudan area. In all these areas spate irrigation operates in locations largely characterized by rural poverty and if well managed can make a substantial difference.

Then Gash, Baraka and Takor other spate irrigation areas in Sudan are Khor Abu Habil in Kordofan and Derudeb in the Port Sudan area Wadi Azum and Wadi Hawar are the largest wadis in Western Sudan, with an estimated annual runoff of 500 to 750 mcm, respectively. In addition, there are more than 300 small local wadis scattered in the Red Sea region and the Savannah belt. The runoff from these wadis partly infiltrates into the alluvial deposits, and partly evaporates. In the Sudan, there are three types of flood irrigation: (1) diversion of flood water from a seasonal khor (stream) such as Khor Abu Habil through canals and then into basins that encompass the farms; (2) flush irrigation that occurs at deltas suchas those formed by the Gash and Baraka seasonal streams in the northeastern parts of the country. The Gash flood water is controlled through canals that irrigate farms (Kirkby, 2001). Since Baraka flow is irregular and has no permanent channel, it is difficult to build canals to control its water (Allan, 1948). Therefore, Baraka's flush irrigation water is left to spread over land covered by flood water which is different from one year to another; and (3) in the northern part of the Sudan, the River Nile overflows its banks and fills depressions called "ahwad" (basins) through canals. These flood waters remain in these basins for 30 days, and then return to the river through drainage canals (Allan, 1948). In general, flood irrigation constitutes14% of irrigated agriculture in the Sudan (Mehari et al, 2007:116). Flood irrigation schemes in the Sudan, similar to other forms of irrigated agriculture, have experienced a number of problems and a decline of crop productivity since the early 1990s (Ibrahim 2008; Kirkby 2001; Narayanamurthy et al, 1997). For example, the Gash Delta has seen a shrinking of the area of cultivation and degradation of the physical environment (IFAD2010; Kirkby 2001). In eastern Sudan, Kirkby (2001) found that sedimentation of fields through flood water poses a great problem as it causes the rise of the field level and impairs the rate of infiltration. He mentions that the average accumulation of sediment is around 40mm per year. Accumulation of sediment in the Gash Delta around Kassala has forced some of the farmers to abandon fields raised.

Tokar must rank as one of the most complicated and marginal spate system anywhere in the world. The total irrigable area on the Tokar Delta is around 80,000 hectares with the peak use amounting to around 52,000 hectares – which was in the early part of the last century. Over time this has been reduced significantly with only about 12,000 ha sown in 2007-2008 season. Originally the scheme was developed for cotton, but nowadays farmers mainly grow sorghum for which they can afford the inputs. The soils of the Tokar Delta comprise fertile silty deposits close to the Barka river and its past flood routes, mainly in the Middle Delta and sandy soils to the south (Eastern delta) and saline silt- clay in north-eastern parts parallel to the sea (Western Delta). Scattered across all parts of the Delta there are raised areas of migrating sand dunes.

In recent years, the river and irrigation infrastructure has deteriorated and become inefficient. In critical areas the earth embankments used for protecting the banks of river channels and diverting the flow of flood waters to the agricultural lands are not reliable, leading to considerable losses of irrigation water. Much of the works undertaken by the Government have been constructed using force account as and when machinery becomes available. No surveys and engineering designs are made and there has been limited scope to introduce more appropriate spate type lower cost structures. This gives the works a limited lifespan and many have to be repeated every 1-2 years.

Table 2.2: Rift basins of the Sudan

River or Wadi	1 Catchment area Km2	2 Sediment Km3	3 period of deposition my	4 Rate of deposition mm yr-1
White Nile rift (alternative A):				
1. Abu Habil	80800	23000	12	0.04
2. Wadi Adar and Yabas	12960	57600	17	0.06
3. Unknown (probably the Blue Nile)	86400			
White Nile rift (alternative B):				
1. Abu Habil	80800	23000	12	0.04
2. Wadi Adar and Yabas	12960	57600	17	0.06
3. Sobat	46400			
4. Blue Nile	40000			

Source: Salama, R.B. (1997)

(1) Rate of denudation 26 m3 Km-2 yr-1.

(2) Column 1 direct measurement of catchment areas from topographic sheets.

(3) Column 2 calculated from average thickness of Tertiary deposits.

(4) Column 3 calculated by multiplying column 1 by denudation rates and dividing the result by column2.

(5) Column 4 calculated by dividing the annual rate of deposition by the sedimentary basin area.

2.6 Problems of Spate and Khor Abu Habil Scheme

Flood or spate irrigation is practiced in many parts of developing countries. The risk with spate irrigation is high, because the flood water is not equally distributed throughout the system. In most cases farmers do not use fertilizers because of the nutrient rich sediments brought by the annual flood water. On the other hand, one of the main problems of spate irrigation is the accumulation of sediments in the fields that causes the rise of the field level which, in turn, does not allow the entrance of the flood water into the fields. Accumulation of sediment has forced some farmers of eastern Sudan to abandon their increasingly elevated fields.

Flood irrigation schemes in the Sudan, similar to other forms of irrigated agriculture, have experienced a number of problems and accompanied by a decline in crop productivity since the early 1990s. For example, the Gash Delta has suffered from shrinkage of the irrigated areas accompanied by a degradation of the physical environment. In eastern Sudan, sedimentation of fields through flood water poses a great problem as it causes the rise of the field level and impairs the rate of infiltration where the average accumulation of sediment is around 40 mm per year. Finally, Khor floods are characterized by high spatial and temporal fluctuation. In some years flood waters fall short of plant needs and in others there may be excessive flooding to the extent that damage is caused to nearby villages and infrastructure as was evidenced in 2007 in Khor Abu Habil and in 2003 in the Gash Delta. (SWECO, 2013)

From a management perspective, Khor Abu Habil Scheme has been beset by a range of financial, administrative and environmental problems which have adversely affected productivity and hampered its main objective since the early 1990s to the present. This has resulted in low crop productivity. A study carried out by the State of North Kordofan in 2007 mentioned that average sorghum productivity for the period 1970-1980 was 12 sacks per feddan and now has been reduced to 3 sacks per feddan. For the same period cotton productivity was reduced from three kantars per feddan to one kantar per feddan (one kantar equals 100 lb). As a result, many farmers have either abandoned cultivation or rented their lands to agricultural laborers.

One of the most serious problems that farmers face in the Khor Abu Habil Scheme is financial support and a lack of credit. The Nuba Mountains Agricultural Corporation was established in 1968 to provide administrative and agricultural services to the farmers of the Khor Abu Habil Scheme. In 1992, with the adoption of the free market and privatization policy by the Sudan government the partnership system was changed and the para-statal agencies abolished. In turn, the cost of agricultural operations became the responsibility of farmers.

On many occasions the return on the sale of cotton is far less than the cost of production. For this reason, many farmers were unable to repay their debt and consequently, they either abandoned their farms or rented them to sharecroppers. Hardship is becoming increasingly common in the Sudan and affects many farmers who borrow money from banks and are unable to repay their debts. Owing to this fact, the Sudan Agricultural Bank and other lending institutions refused to finance cotton cultivation at Khor Abu Habil Scheme for the seasons 2008 and 2009 and when cotton cultivation ceased, cultivable land of Semeih section dropped by 23% from 13,000 feddans to 10,000 feddans.

a) Abu Habil spate irrigation (past studies): Some important studies were conducted in the past for development and later for improvement of performance of El semaih Irrigation project. These studies includes: Study of Mr. D Fagda – Soil conservation expert-1944 , Group Doxiades study (1963/1966), Italian study (1988-1991), FAO - food security programs study (2002), Yam Consulting Group study (2003), Design review Study - Ministry of Irrigation (2006), and Study of the Ministry of Agriculture, Livestock and Irrigation North Kordofan state 2007. The important outcomes of these studies can be summarized as follows:

b) Study of Mr. D Fagda – Soil conservation expert-1944: proposed the idea to execute the project. The project will started with the assumption that the incoming flow is in the range of 15 million m3 and the supply water to be stored in Rahad Turda via a canal and by making embankment in the eastern side of the Rahad Turda. This water may used for an initial proposed project area of three thousand feddan as experimental area which can be expansion after studying the Khor and the nature of the flooding.

c) **Group Doxiades study (1963/1966):**highlighted basic information about the watershed and sources of water supply, and showed that: (1) Rahad Turda is supplied from Kor "Umm Tgergr". (2) The Annually average amount of water received from Khor "Umm Tgergr" amounts to 8 million cubic meter and ranging from 4-35 million m^3. (3) Annually average amount of water of Khor Abu Habil is 90 million m^3, ranging between 23 - 295 m^3. (4) There is no relation between flood of Khor Umm Tagerger and that of Khor Abu Habil.

d) **Italian study (1988-1991):** It is a comprehensive study and concluded that:

1. Area suitable for irrigation is estimated as 60 thousand feddans.
2. Annual water supply of Khor Abu Habil is estimated as 87.6 million m^3 at Rahad regulator (with 80% probability level).
3. This amount can be divided into 10 million m^3 at upstream Rahad regulator and 11 million m^3 for downstream El Sameih divider.
4. Available water supply for the existing projects along Khor Abu Habil can be estimated as 66.6 million m^3.
5. The amount of water that comes via Khor "Umm Tagerger "a tributary that supply Rahad Turda" is about 6 million m^3.
6. The estimate of annual water losses is about 39.5 million m^3 (seepage and evaporation, drinking water, small irrigation projects around, Rahad Turda, livestock consumption).
7. Water available for irrigation projects may be estimated as about 27.1 million m^3. This study constituted the basis for all subsequent studies, and did not propose to change the irrigation system, but recommended to improve the efficiency of spate irrigation by minimizing the size of basin from 40 to 12 feddans.

e) **FAO - food security programs study (2002):** the most important features of this study are:

1. Focused on the results of the Italian study and the review study made by Ministry of Irrigation and Water Resources in 2006.

2. Concentrated on proposing technical view to improve irrigated agriculture and diagnosing hinders of production and improving water management and soil aspects.

3. Identified soil and water management obstacles facing crop production in the existing projects (Semeih / Rahad / vegetable farm) and their extensions.

4. Submitted proposals regarding irrigation systems and water management and presented two models (spate irrigation - supplementary irrigation) and gave comparison between them in terms of the amount of water used, agricultural operations and expected production of the existing projects and extensions.

5. Studied some valleys and Khors that feed the Khor Abu Habil.

f) Yam Consulting Group study (2003): The study aimed to establish a work plan for the development and use of water of Khor Abu Habil Basin and gave the following conclusions in reference to surface water resources:

1. KhorAbu Habil originates from Nuba Mountains at South Khordofan State and flows along the southern curtains of North Khordofan State and discharges its water in the dune area extended along Tandalti area.

2. Khor water is discharged in White Nile at the rare high flood.

3. Identified Khor basin area as 26,792 m^2.

4. Annual average runoff of Khor Abu Habil, Kagar, and tagerger in El Rahad is 161 million m^3.

5. Main tributaries of the Khor are Kagar and tagerger which meat nearby El Rahad.

6. The study suggested evaluating and rehabilitating water resources and improving flow measuring stations and irrigation system and improves infrastructure and main roads.

7. In Contrast to previous studies this study pointed out that Khor tagerger discharge its water directly into the Turda and do not meet Khor Abu Habil.

g) Design review Study of the Federal Ministry of Irrigation (2006):

This study was carried out recently and the most important features that distinguish it from previous studies are:

1. Specification of the cost of the rehabilitation program and its various components.
2. Estimated water demand for El Rahad Al a Khdir, vegetables, and Semeih irrigation projects as 44 million m^3.
3. Specified the project proposed extension area.
4. Set priorities and schedule for implementation of the rehabilitation work.
5. Pointed problems facing water management and irrigation in the project.

h) Study of the Ministry of Agriculture, Livestock and Irrigation North Kordofan state (2007): The study concentrated on the current situation, constraints, and visions for the future. It proposed a detailed rehabilitation and investment programs.

i) Abu Sidir Study (2013): the study is directed to analyze the existing performance and mode of operation in El Semih agricultural scheme, which is one of the old spate systems in Sudan. From the results that indices of irrigation efficiency, crop productivity, area utilization efficiency, budget allocation, and water use efficiency are low due to poor system of water management. The equity indicator is low reflecting existence of top-tail ends problem in the project and adequacy of supply can be described as poor and function of available rain water. The study also reveals that low sediment removal rate (high sediment concentration) is found at reaches located at canal top and more sediment deposition occurred at these reaches (non uniform head- tail sediment distribution) due to the mode of water distribution. As conclusion the study recommend to improve the existing mode of water management and distribution, study alternative schemes to store water and select the most feasible method for sediment control.

j) SWECO-Study (2013): The study for development and management to Khor Abu Habil catchments. The river is the only surface water available in the area and the flow is limited and the direct water demand will increase substantially during the coming 20 years. The increase is significant and is mainly a consequence of the current plans to develop large-scale extensions of irrigation schemes.

Used mike basin to water balance model .the model is a convenient tool for simulation and testing of various scenarios and development options. The results of such simulations provide decision makers with the necessary information that enables them to make decisions to solve identified problems through a both specific area approach but also the perspective of the entire river basin. The fact that the model operates within the given physical constraints will ensure that selected options are realistic and achievable.

The initial situations were considered in the water balance model, one describing the present situation, scenario 2012, and one describing a future situation, scenario 2030, where an increased population poses higher water stress on the water resources.

The result of the water balance analysis shows that there is a need for a strengthened water supply infrastructure to ensure the supply of water to cover the future water demand in the area.

The dam development scenario addresses these problems and gives a good water supply to the upper catchment but increases only to some extent the water supply in Lower Abu Habil. To reach a balanced water supply/demand in the whole catchment a reduction of the planned irrigation schemes in the whole area will be needed.

CHAPTER THREE
3. MATERIALS AND METHODS

3.1 Description of Khour Abu Habil Catchment Management Area

3.1.1 Location of Abu Habil Catchment in North Kordofan:

Khor Abu Habil originates in the Nuba Mountains of Southern Kordofan and is one of` the largest seasonal streams in the Sudan (Figure 1). Located between latitudes 12° 15' N and 13° 00' N and longitudes 30° 30'E and 31° 15' E it occupies an area of 26,792 m^2. It flows eastward and drains into the sandy soil and dunes near the town of Tendelti. In exceptionally high floods it flows beyond Tendelti and drains into the White Nile. High floods in Khor Abu Habil are associated with flood hazards to neighboring villages and the destruction of infrastructure and earth dams (Abu Sidir, 2013).

3.1.2 Study Area Physiographic Setting

The Abu Habil catchment is forming/feeding an ephemeral (seasonal) river with an approximately four-month run-off period between July and October. Such rivers are referred to as khors or wadis, It is one of the largest seasonal rivers in Sudan. Its origin is in Nuba Mountains in South Kordofan and it flows through North Kordofan and drains into an alluvial fan in the White Nile State. The catchment is located approximately 400 km southwest of Khartoum.

The River basin has been divided into 5 major sub-basins, namely: Khor Kajeer, Khor Tagor, Khor Umm Tagerger, Central Abu Habil, and Lower Abu Habil. Freshwater bodies represented within the catchment, include the Rahad Turda and Sherkela Turda.

The Khor Abu Habil catchment area is characterized as a flat plain with some local variations mainly in the upstream parts of the tributary khors. The main features of the study area are flat silty/clayey plains, rocky outcrops in the eastern Nuba Mountains, isolated hills and seasonal streams.

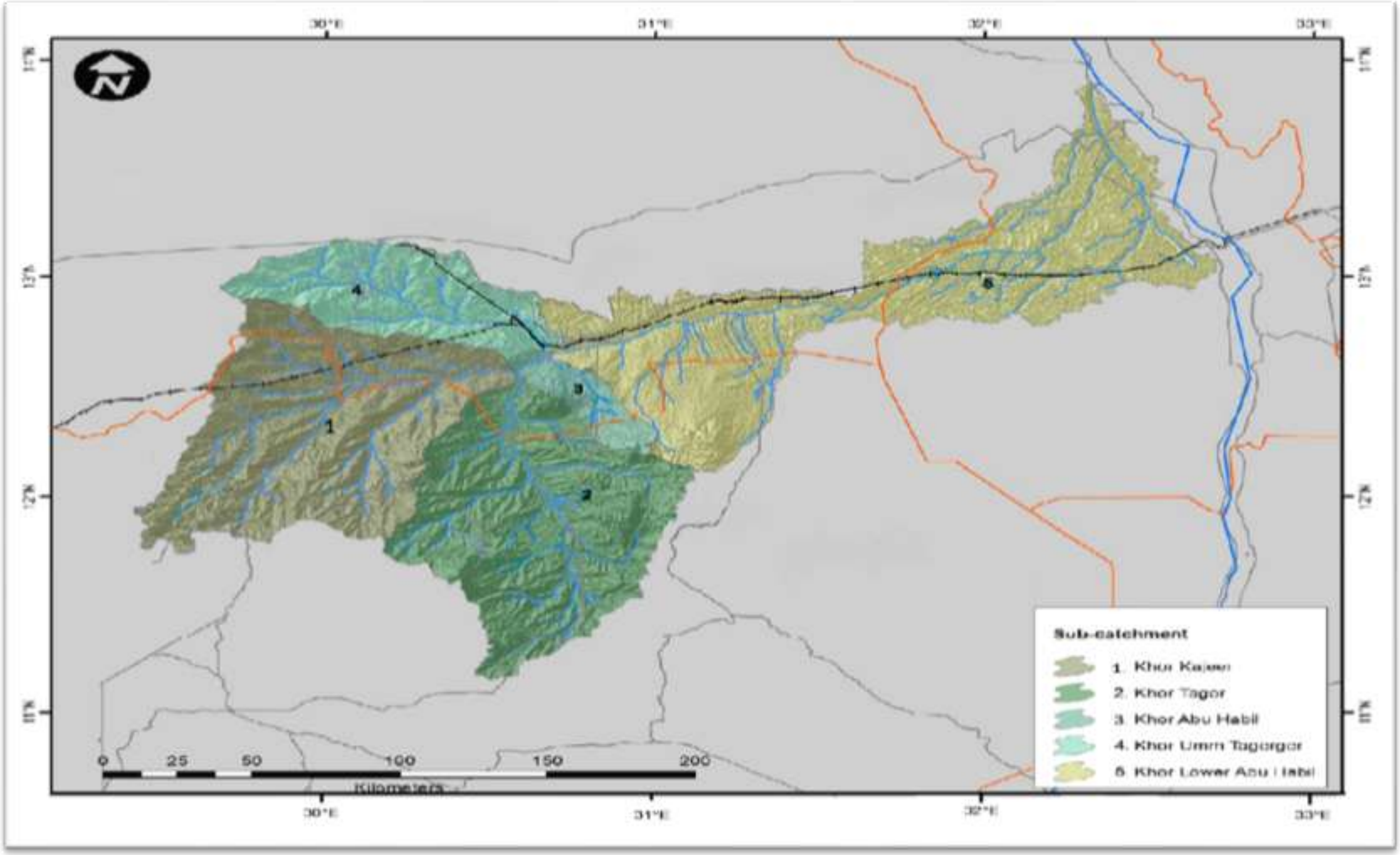


Figure 3.1: Location and Extent of Khor Abu Habil Catchment Area
Source: SWECO Study (2013)

3.1.3 Topography ,soil and climate:

1) **Topographic characteristics:** Abu Habil area is a flat plain except for a few differences due to the conversion of some local water courses and the side effects of erosion and drainage towards the main valley in addition to the presence of scattered highlands and small natural depressions. The area has a slight slope (0.1%) from west to east towards the Nile, and the level of height above sea basin is between 260 meters in southern Kordofan to 475 meters when it reaches El Rahad; and 445-446 meters above sea level at Um Rawaba.

There are two branches of the main water course, Um Tagerger and Kajar, which meet at El-Rahad to form the main course of Abu Habil. Before Um tagerger meets Abu Habil it forms a large swamp that is known by Tordat El Rahad .

2) Soil:

Most of the land plain of Abu Habil is made of new deep sedimentary clay soil that is dark black or brown gray in color, which is homogeneous along the sector with strong to average configuration. The Soil has very low drainage because its composition varies from muddy to silty muddy loam with clay (40-60 %) and silt (30-40 %) .This also affects the physical and chemical properties of the soil .The soil is characterized by high catonic exchange and this favors supply of nutrients to plants. The soil is saline or non-sodic and therefore there are no salinity problems. The proportion of the available phosphate and nitrogen are low and requires important interventions to ensure a reasonable extent of soil fertility and productivity Potassium is high.

The ability of soil to retain water is high but the rate of permeability within the soil profile is weak and ranges from 0.1 to 0.5 cm / hour, .Poor drainage is one of the fundamental problems of this soil, and can raise the rate of exchange to 1-2 cm / hour .

3) **Climate:**

The study area is described as semi-dry low rainfall area (Abu Sidi, 2013). Average annual rainfall is 380 mm and the rainy season runs from May to October and reaches its maximum in July or August as the average of two months represents 69% of the total annual rainfall. Maximum rate of rainfall during the past decades was recorded in 1946, where it reached 982 mm, while the lowest rate (96 mm) was in 1984.

Mean monthly temperatures vary between 22 to 31 degrees Celsius, while the average maximum temperature varies between 30°C in December / January to 39°C in June. The average minimum temperature ranges between 13°C in January to 24°C Celsius in May / June .The temperature is suitable for most crops grown In summer, but high temperature increases evaporation. The average annual relative humidity is 24% and monthly rates range from as low as 30% in to as high as (73%) in August.

The area is affected by the rainy south westerly winds that begins in July and ends in September, while the dry northeast winds are prevalent during the months of November to April table (3.1) shows Khor Abu Habil Station measured monthly data averaged over fifteen year records.

Table (3.1): EL-Obeid measured monthly data records

Month	Parameter					
	Min. Temp. C°	**Max. Temp. C°**	**Rain mm**	**Humidity %**	**Wind km/day**	**Sun shine (hours)**
January	13.5	30.5	0	27	216	10.3
February	14.5	31	0	23	242	10.5
March	18.2	35.6	0	19	216	10.9
April	21	38.2	2	21	190	10.2
May	24	39	14	30	216	9.6
June	24.2	37.2	27	44	242	8.3
July	22.8	33.3	113	61	242	7.1
August	21.8	31.3	143	72	190	6.8
September	21.5	33.7	68	63	164	8.3
October	21.2	36.1	19	41	190	9.4
November	17.5	33.8	0	29	216	10.2
December	14.1	30.8	0	30	216	10.6

Table (3.2): Kosti measured monthly data records

Month	Parameter					
	Min. Temp. C°	**Max. Temp. C°**	**Rain mm**	**Humidity %**	**Wind km/day**	**Sun shine (hours)**
January	16.6	32.8	12	39	164	10.2
February	17.3	34.5	20	33	164	10.4
March	20.1	37.2	82	28	164	10
April	22.5	40.5	128	26	138	10.2
May	24.8	40.5	186	35	138	8.3
June	24.8	38	173	47	164	8.4
July	23.2	34.5	222	62	164	7.1
August	22.5	32.3	261	73	138	7
September	22.5	34.5	200	68	138	8.2
October	22.8	37.1	174	52	86	9.2
November	21	36.1	61	40	138	10
December	17.5	33.2	22	42	164	10.3

Table (3.3): Rashad measured monthly data records

Month	Parameter					
	Min. Temp. C°	Max. Temp. C°	Rain mm	Humidity %	Wind km/day	un shine (hours
January	18.8	32	0	45	268	10.6
February	19.2	32.6	0	46	268	10.8
March	22.6	35.7	1	40	216	10.9
April	22.6	36.3	10	44	242	10.8
May	22.8	35.6	64	48	216	10.3
June	21.1	33	104	60	242	8.8
July	20.5	30.2	159	68	242	6.8
August	20.1	30	189	73	216	6.3
September	19.7	30.6	158	70	216	8.1
October	20.2	32.2	95	62	242	8.2
November	20	32.7	2	45	268	10.4
December	18.8	31.8	0	46	268	10.6

Source: Data from Fao.org. Climate

3.1.4 Ground Water

In this study it is assumed that groundwater abstraction is kept at a low level to avoid future unsustainable exploitation of the groundwater resources. Further investigations are required to explore the capacity of the groundwater production in each sub-catchment.

3.2 Collection of Input Data

3.2.1 Study Satellite Data

Satellite Data for the study includes: the daily data (air temperature, precipitation, wind, and relative humidity) have also been downloaded from http://globalweather.tamu.edu/# website in CSV fill format for a given location,(South Latitude (11),West Longitude (30), North Latitude (15), East Longitude (32)) and time period, (1/1/1980 to 12/31/2012). The number of downloaded weather stations was 44 points Fig. (3.1), however, the points that cover the grid station (GS) boundary were 40 points Fig. (3.2). Table (3.4) shows the Weather Station No.24 monthly data averaged over thirty years as a sample. Appendix I shows the monthly data averaged over thirty years for all 44 Weather Stations.

Table (3.4): Weather Station No.24 monthly data averaged over 30 year records

Month	Parameter				
	Max. Temp. C°	Min. Temp. C°	Rainfall (mm)	Wind Speed (m/s)	RH%
Jan	33.017	14.384	0.022	0.258	3.734
Feb	33.215	15.379	0.004	0.164	3.495
Mar	40.201	20.163	0.249	0.135	3.647
Apr	42.209	22.306	1.199	0.131	2.912
May	43.109	26.062	29.394	0.264	2.75
Jun	39.7	25.994	21.373	0.38	3.227
Jul	36.25	24.785	114.632	0.571	3.384
Aug	36.235	23.887	124.891	0.627	2.879
Sep	38.857	23.856	49.39	0.487	2.395
Oct	40.878	24.655	8.581	0.309	2.493
Nov	36.191	18.791	0.146	0.234	3.163
Dec	33.185	15.171	0	0.284	3.532

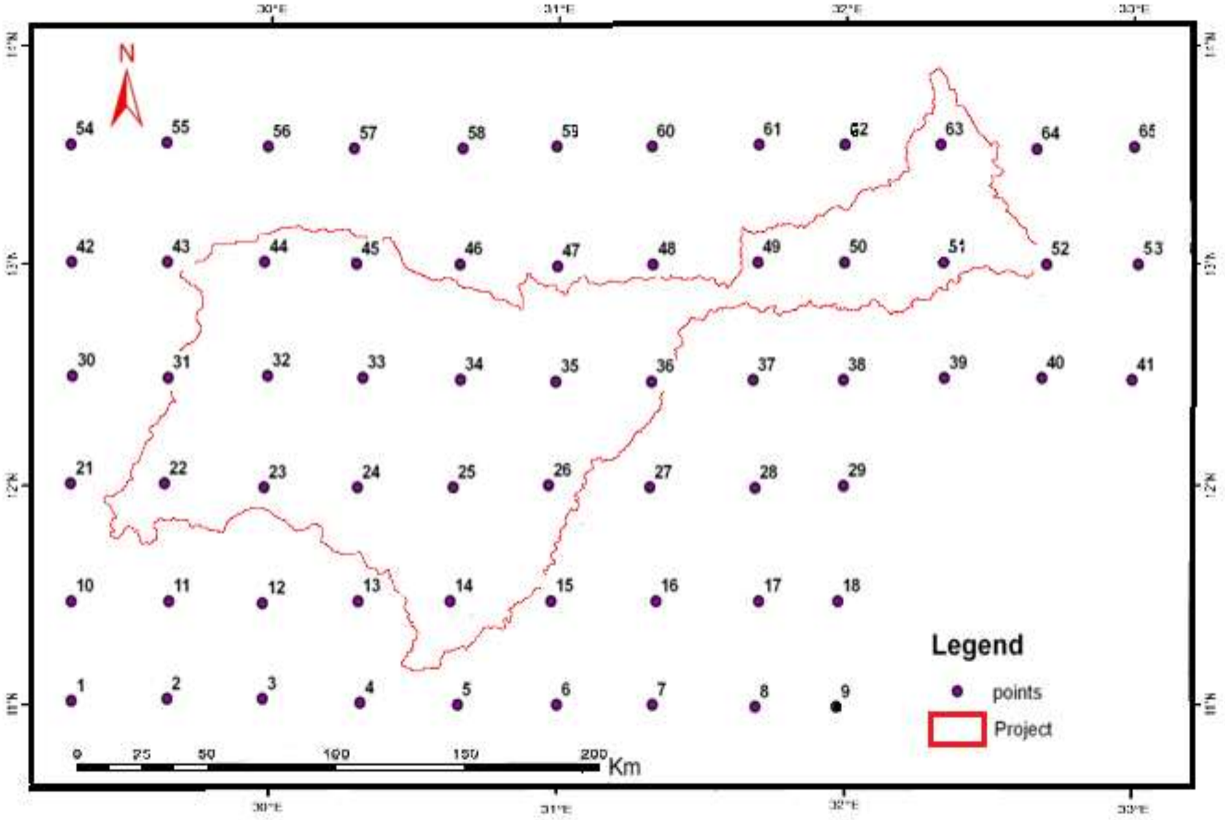


Figure 3.2: Location grid of stations used to download climatic data over the study area

Records used for the analysis have ended at the same year, and there are no gaps in the records. Various software was used in this study, FAO CROPWAT 8.0 software, GIS software, (ArcGIS 9.3) and Microsoft Office (Word and Excel). In addition, Computer System, Microsoft Windows 7 Ultimate, Version 2009, Service Pack 1, Product ID, 00426-OEM-8992662-00010 was also used for this study.

3.2.2 Calibration of Satellite Climatic Data (Weather Station Data) Using Double mass Analysis:

Before using the downloaded weather stations data (air temperature, precipitation, wind, and relative humidity) for analysis, they had been calibrated. The calibration has been carried out by comparing the ground data of El-Obeid Station and the closest downloaded weather station, Station No.24, in order to calculate the correction values for weather station data calibration. The Weather Station N0.24 has been taken as the model of calculation for all parameters. Microsoft Office Excel spreadsheets were used for calculation as shown in the following paragraphs:

The purpose of the double mass analysis is to display errors or in-homogeneity in data series. In-homogeneities were detected through changes in the slope of the curve from a certain point in time. The principle was based upon comparing running accumulative rainfall between one or a set of reference stations and a test station. The double mass analysis can be used to correct for inconsistencies by multiplying with a correction factor which is the ration of the slopes for the period in question before and after the adjustment. Rainfall data is accumulated only for the common period of data..

In the case of the Khor Abu Habil river basin, the Rashad, EL Obied and kosti station is used as the main independent and reference station due to the fact that it does not present any gaps during the entire period from 1980-2012. The determination coefficient, r^2, presents high values, indicating a satisfactory correlation between them, (Table 3.5)

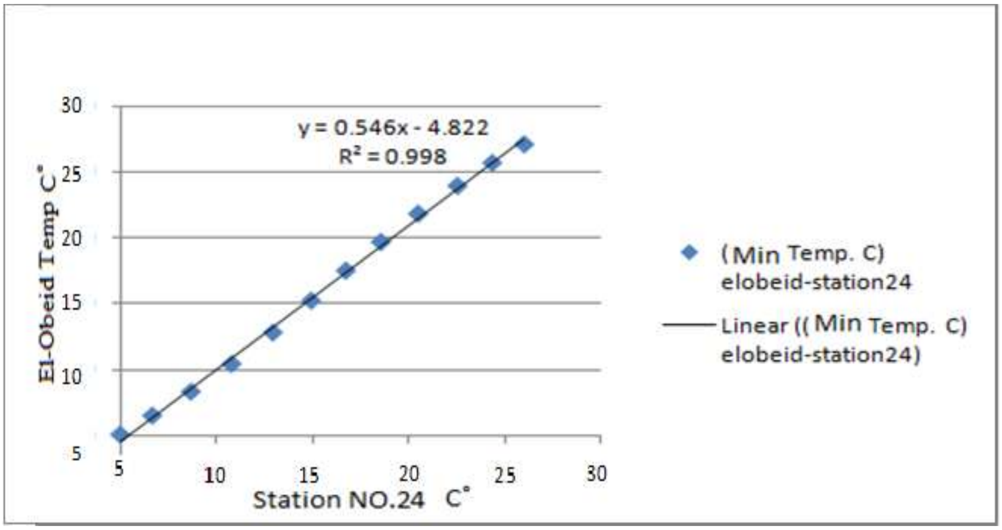
Table 3.5: Determination Coefficients for the Double Mass curve analysis

Reference and Test Station	Determination coefficient
Elobeid - Station NO.1	0.901
Elobeid - Station NO.2	0.912
Rashad - Station NO.3	0.905
Rashad - Station NO.4	0.906
Rashad - Station NO.5	0.907
Rashad - Station NO.6	0.917
Rashad - Station NO.7	0.923
Rashad - Station NO.8	0.919
Rashad - Station NO.9	0.929
Kosti - Station NO.10	0.850
El-obeid - Station NO.12	0.916
El-obeid - Station NO.13	0.908
El-obeid - Station NO.14	0.920
El-obeid - Station NO.15	0.906
El-obeid - Station NO.16	0.923
El-obeid - Station NO.17	0.901
kosti- station NO.18	0.871
kosti- station NO.19	0.869
kosti- station NO.20	0.879
kosti-station NO.21	0.882
El-obeid - Station NO.23	0.870
El-obeid - Station NO.24	0.862
El-obeid - Station NO.25	0.863
El-obeid - Station NO.26	0.908
El-obeid - Station NO.27	0.923
El-obeid - Station NO.28	0.867
Kosti - Station NO. 29	0.886
Kosti - Station NO.30	0.866
Kosti - Station NO.31	0.892
Kosti - Station NO.32	0.887
El-obeid - Station NO.35	0.850
El-obeid - Station NO.36	0.867
Kosti - Station NO.40	0.884
Kosti - Station NO.41	0.879
Kosti - Station NO.42	0.864
Kosti-Station NO.43	0.859

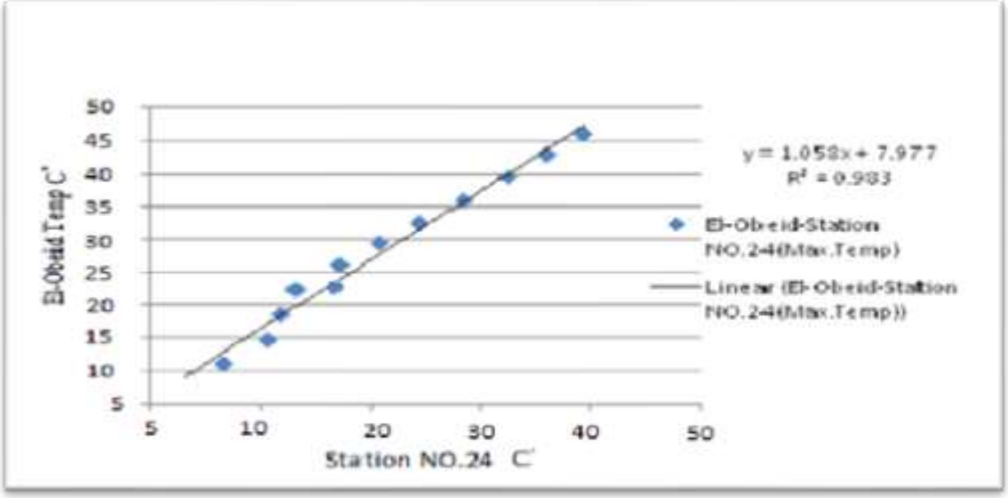
Example (for station NO. 24):

i. **The Minimum and Maximum Temperature**:

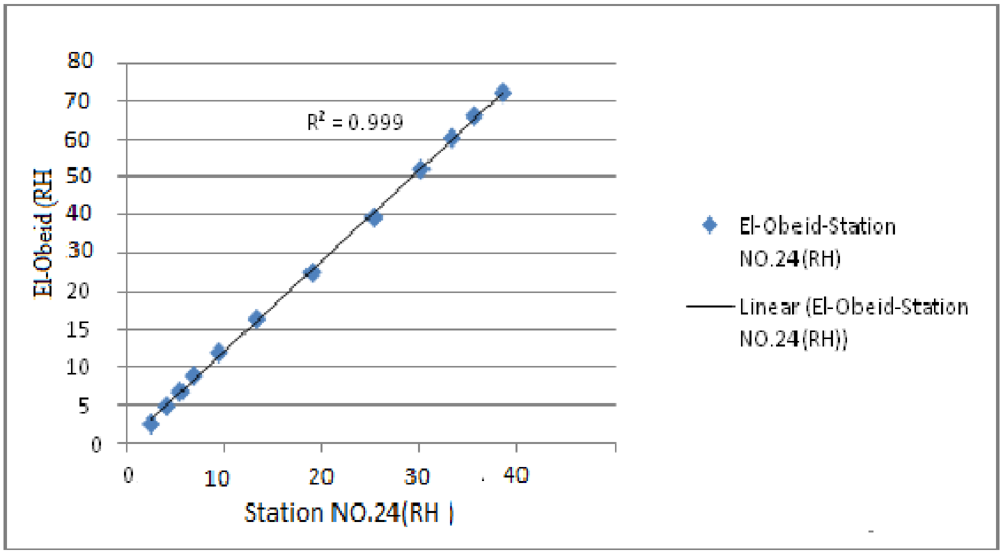
Minimum Temperature



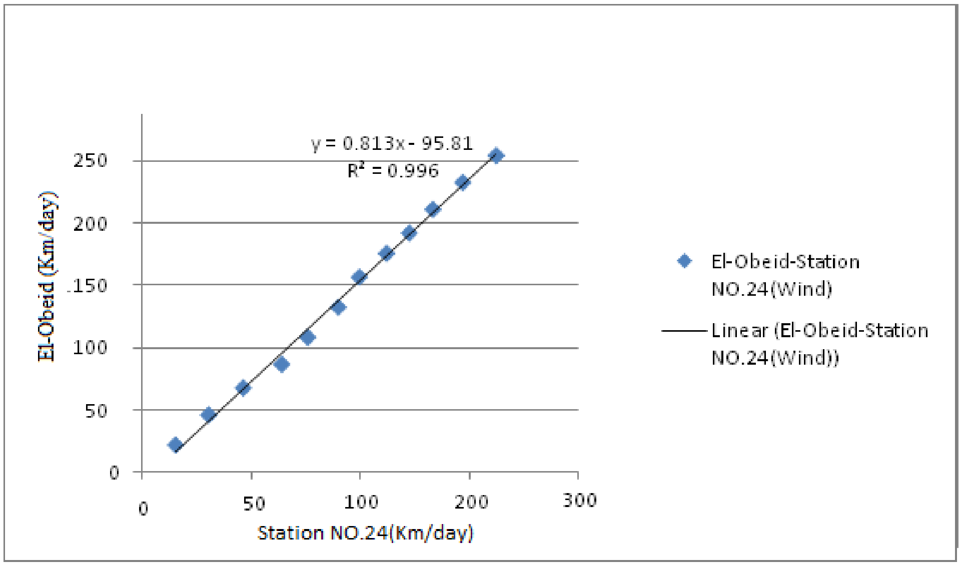
Maximum Temperature



ii. Relative Humidity:



iii. Wind Speed:



iv. Rainfall:

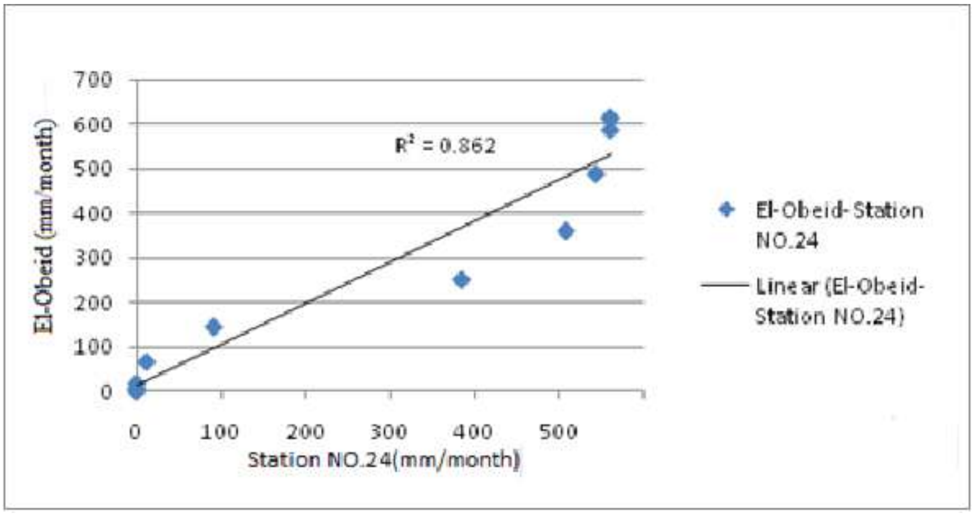


Figure3.3: Example of comparison of Station NO.24 generated and Obeid measured climatic data

3.2.3 Forecast of Climate Data and Stream Flow Rate (Time Series Analysis):

To estimate climate in 2030 using statistical analysis of time series, autoregressive–moving-average (ARMA) models provide a parsimonious description of a (weakly) stationary stochastic process in terms of two polynomials, one for the auto-regression and the second for the moving average.

ARMA models can be described by a series of equations. The equations are somewhat simpler if the time series is first reduced to zero-mean by subtracting the sample mean. Therefore, we will work with the mean-adjusted series

$$y_t = Y_t - \overline{Y}, \qquad t = 1, \cdots N \tag{1}$$

Where Y_t is the original time series, Y is its sample mean, and y_t is the mean-adjusted series. One subset of ARMA models are the so-called autoregressive, or AR models. An AR model expresses a time series as a linear function of its past values. The order of the AR model tells how many lagged past values are included. The simplest AR model is the first-order autoregressive, or AR(1), model

$$y_t + a_1 y_{t-1} = e_t \tag{2}$$

Where y_t is the mean-adjusted series in year t, yt-1 is the series in the previous year, at is the lag-1 autoregressive coefficient, et and is the noise. The noise also goes by various other names: the error, the random-shock, and the residual. The residuals et are assumed to be random in time, and normally distributed. Be rewriting the equation for the AR (1) model as

$$y_t = -a_1 y_{t-1} + e_t \tag{3}$$

We see that the AR(1) model has the form of a regression model in which yt is regressed on its previous value. In this form, a1 is analogous to the negative of the regression coefficient, and et to the regression residuals. The name autoregressive refers to the regression on self (auto). Higher-order autoregressive models include more lagged yt terms as predictors. For example, the second-order autoregressive model, AR(2), is given by

$$y_t + a_1 y_{t-1} + a_2 y_{t-2} = e_t \tag{4}$$

Where a_1 , a_2 are the autoregressive coefficients on lags 1 and 2. The p^{th} order autoregressive model, AR(p) includes lagged terms on years t -1 to t -p .

The moving average (MA) model is a form of ARMA model in which the time series is regarded as a moving average (unevenly weighted) of a random shock series et . The first-order moving average, or MA(1), model is given by

$$y_t = e_t + c_1 e_{t-1} \tag{5}$$

Where e_t e_{t-1} are the residuals at times t and t-1, and c1 is the first-order moving average coefficient. MA models of higher order than one include more lagged terms. For example, the second order moving average model, MA(2), is

$$y_t = e_t + c_1 e_{t-1} + c_2 e_{t-2} \tag{6}$$

The letter q is used for the order of the moving average model. The second-order moving average model is MA(q) with q = 2 .

We have seen that the autoregressive model includes lagged terms on the time series itself, and that the moving average model includes lagged terms on the noise or residuals. By including both types of lagged terms, we arrive at what are called autoregressive-moving-average, or ARMA, models. The order of the ARMA model is included in parentheses as ARMA(p,q), where p is the autoregressive order and q the moving-average order. The simplest ARMA model is first-order autoregressive and first-order moving average, or ARMA :

$$y_t + a_1 y_{t-1} = e_t + c_1 e_{t-1} \quad (7).$$

The generated climate data for the year 2030 using ARMA is estimated for each weather station and sample of the data for station number 24 is shown in table 3.6

Table (3.6): Forecasted monthly data for Weather Station No.24 for the year 2030

Month	Parameter				
	Max. Temp. C°	Min. Temp. C°	Rainfall (mm)	Wind Speed (m/s)	RH%
Jan	34.126	14.804	0.038	0.295	2.096
Feb	35.074	16.416	0.005	0.189	1.981
Mar	42.363	19.477	0.601	0.162	2.101
Apr	44.472	20.384	1.582	0.170	1.733
May	44.617	24.525	25.599	0.300	1.795
Jun	40.542	26.219	21.519	0.393	2.267
Jul	36.371	25.621	90.785	0.585	2.281
Aug	35.108	24.895	111.095	0.637	2.013
Sep	38.421	24.713	50.746	0.487	1.718
Oct	43.554	24.917	14.329	0.337	1.585
Nov	38.213	19.085	1.550	0.258	1.888
Dec	35.316	15.748	0.000	0.320	2.013

3.2.4 Water Demand

a. Cropping Patterns and Estimation of Water Requirements

The water requirements for three cropping pattern (sorghum, cotton, tomato) have been calculated by CROPWAT.

The calculation of crop water requirements is based on the so called “Reference Evapotranspiration” (ETo). The evapotranspiration of the crop (ETc) is calculated by applying a factor to the reference evapotranspiration, which depends on the crop and its state of growth.

The ETo can be derived in two ways, firstly from the Penman-Monteith equation. The input data for this equation is as follows:

1. Average minimum temperature (C)
2. Average maximum temperature (C)
3. Average relative humidity (%)
4. Wind runs (km/day)

5. Hours of bright sunshine (hrs/day)

Unfortunately there are no meteorological stations near to the Abu Habil irrigation area that can provide these data. The second method of deriving ETo is by means of a USDA “Class A” evaporation pan. ETo is calculated as 80% of the evaporation from this pan. The only available evaporation data is using a piche evaporator. Unfortunately it is not possible to relate the evaporation from this device to ETo. Current and proposed irrigation areas (ha) is shown in table 3.7

Table 3.7: Irrigation Areas (base year and proposed) (ha)

Project	Base year areas	Proposed extensions	Total areas
Rahad for vegetables	109	311	420
Green Rahad	1,323	2,478	3,801
Semieh scheme	3,851	1,130	4,981
New extensions	0	6,310	6,310
Total areas	5,284	10,228	15,512

Source: SWECO, 2013

The Food and Agriculture Organization of the United Nations (FAO) maintains a database CLIMWAT with actual and estimated climatic data, including both ETo and rainfall. This has been utilized for the calculation of crop water requirements.

Table (3.8) shows the irrigation water requirements for the existing areas in irrigation scheme using the water requirements for the all year irrigation and estimated irrigation water requirement for new extensions area in scheme for all year irrigated.

Table 3.8: Irrigation Areas Current and Proposed (ha)

Project	Water Demand for Current areas (year 2012)(m^3/day)	Water Demand for Current areas and Proposed extensions (year 2030)(m^3/day)
Rahad for vegetables	12300	50553
Green Rahad	197600	574256
Semieh scheme	699200	916504
New extensions	0	1161040
Total Demand	**909100**	**2702353**

Source: SWECO, 2013

b. Population Water Demand:

Population distribution, density and composition are key factors influencing the demand on water resources

At national and at state levels, population census and estimates are undertaken at regular intervals. In some cases estimates differ a lot between studies. For this study, population information is based on the latest national population census in 2008 so to make sure that information is drawn from a single and verifiable source. Annual growth rate (%) is estimated by the central statistics office

.In this study, the below population projects are based on a long-term average annual figure of 2.5%. Urbanization is on-going and most of the urban immigrants are from South Kordofan state. Hence the national average has been applied as follows: 2.3% in rural areas and 2.7% in urban areas. It must be noted that this approach is adequate for basin wide planning but not for local planning of water supply. The respective unit consumption from Ministry of Water Resources and Electricity (2013) for each level is set as: 50 liters /person/day for yard stands; and 20 liters /person/day for stand posts.

The proportion of the population within the Abu Habil catchment is shown in Table 3.8. Projections of population growth are also given in the same table.

Table 3.9: Population within the Abu Habil catchment

User	Estimated population 2012	Total Water Requirement (2012)lit/day	Estimated population (2030)	Total Water Requirement (2030)lit/day
Tandalti	114800.0	5740000.0	185443.0	9272137.8
Dalang	167100.0	8355000.0	269925.8	13496291.2
Rashad	130700.0	6535000.0	211126.9	10556345.0
El Rahad	364600.0	18230000.0	588958.4	29447922.0
El HamraVillage	69400.0	3470000.0	112105.6	5605281.9
El Semeih Village	60000.0	3000000.0	96921.3	4846065.1
Abu Jebeeha	16300.0	815000.0	26330.3	1316514.3
Shiekan Village	283800.0	14190000.0	458437.8	22921887.7
Kadougli	4800.0	240000.0	7753.7	387685.2

c. Livestock Water Demand

The animal resources within the catchment have been estimated. The livestock populations for 2012 and 2030 have been projected by applying the proposed growth rates, and the corresponding water demand is calculated applying the unit consumption for each category.

The corresponding water demand from Abu Habil is calculated on the assumption that the wet season number of livestock is present in the area and use the Abu Habil surface water for four months.

Similarly to the population projections, the animal populations have been interpolated to the catchment level. Projections were made for the years 2012 and 2030 considering a rate of annual growth According to the information centre belonging to the Federal Ministry of Livestock, Fisheries and Rangelands as presented in Table 3.10.

The water consumption is suggested for livestock as listed in Table 3.11 and estmated water demand in 2012, 2030 in table 3.12

Table 3.10: Estimated water consumption for livestock

Livestock	Growth rates
Cattle	2.8%
Goat	4.3%
Sheep	4.3%
Camel	0.7%
Donkey	0.5%

Source: IFAD, 2010

Table 3.11: Livestock unit consumption

Animal Type	Unit Water Consumption (liters per head per day)
Cattle	25
Sheep	3.3 (approx. 10 every 3 days)
Goats	10
Camel	5 (35 every 7 days)
Horses/donkeys	15

Source: IFAD, 2010

Table3.12: Livestock Total Water Requirement

User	Estimated livestock (2012)	Total Water Req (2012)lit/day	Estimated livestock (2030)	Total Water Req (2030)lit/day
ElDalang Livstock	818700	8774390	1507194.717	15551137.40
Rashad Livstock	657500	6809000	1149679.608	11249094.19
Tandalti Livstockl	622200	6211090	1202420.507	11397327.10

3.2.5 Hafirs Water Storage Facilities

The Abu Habil River basin accounts for a large number of hafirs and minor water storage facilities. These relatively simple structures are very convenient due to their proximity to the user

Table 3.13: Dam and Hafir water capacity

Name	Capacity (Mm^3)
Al Debeibat Dam	4
El Rahad Turda	30
Bangadeed	2
Sesaban Dam	6
Sherkela Turda	2

Source: Ministry of irrigation and Water Resources, 2008

3.3 Nile Basin Decision Support System (NB-DSS), Modeling Tools and Procedure

The steps of uses Nile Basin Decision Support System (NB-DSS) model and tools is given in appendix 2 and figure (3.4) Schematic representation of the NB-DSS flow chart and logic

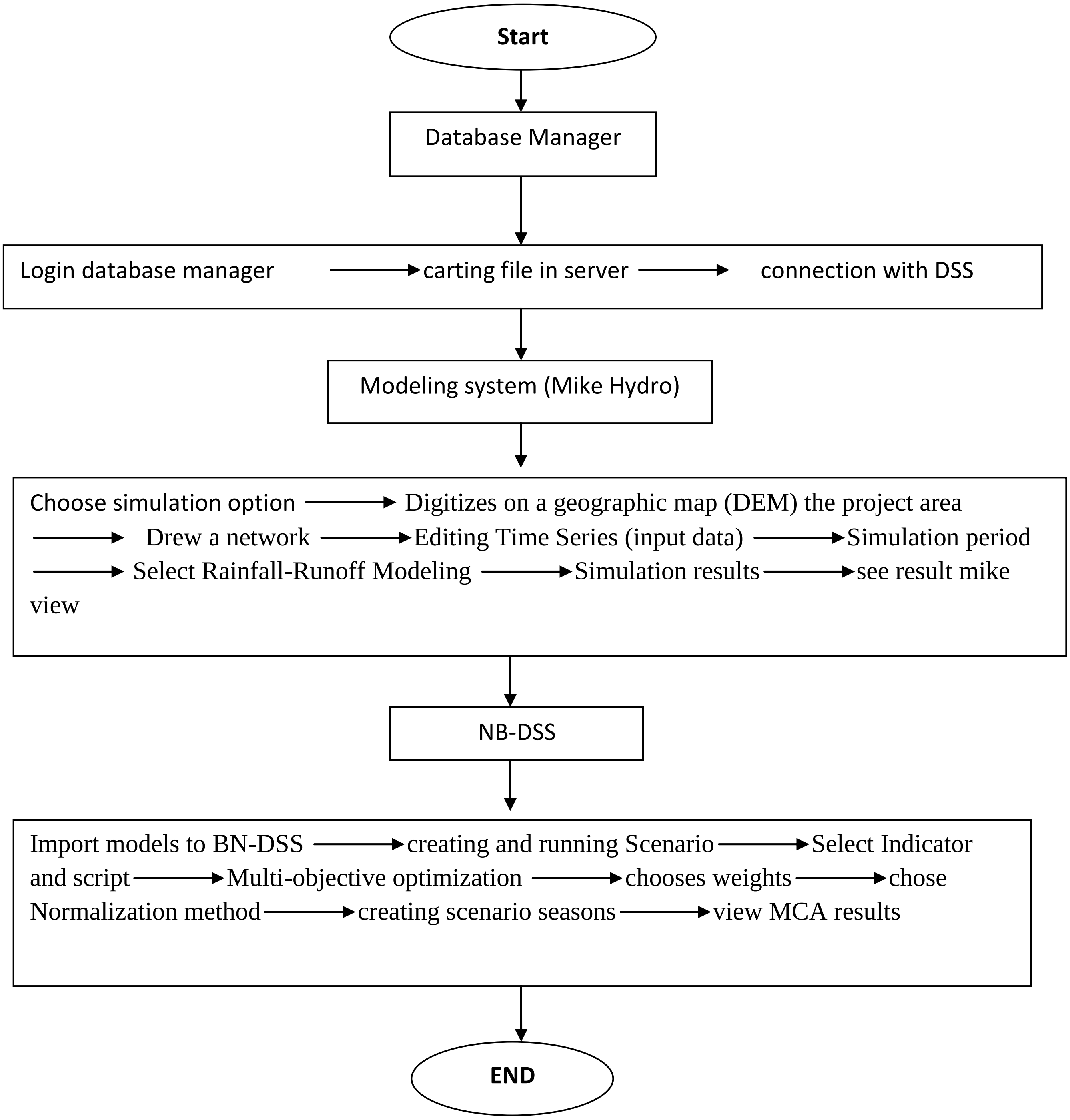


Figure 3.4: Schematic representation of the NB-DSS flow chart and logic

3.4 Other Project Input Data for the Hydrological Model

3.4.1 Records of Wadi Flow Rates

Input data to a hydrologic model are rainfall, water flow, potential evapotranspiration and catchment area. To calibrate the hydrologic model, input data needs to have records for the same time period and preferably a longer period such as at least 10-15 years. This enhances the probabilities that the model is representative for normal, dry and wet years.

In the case of Abu Habil, the rainfall data provide very important information for surface water hydrology assessment because runoff measurements are very difficult to conduct as well as resource consuming and therefore generally scarce. Rainfall is also the most important input for hydrological models, which are utilized to calculate runoff. This can then be compared to short periods of measured runoff at a few locations. Rainfall data has been received from meteorological department. Information regarding the rainfall stations is presented Chapter 2.

Mean annual precipitation varies within the Khor Abu Habil catchment and only two stations, Rashad and El Obeid, have rainfall data for the same period as the water flow for Abu Habil station. Rashad is situated in the south-eastern part of the catchment in the mountainous areas with relatively high rainfall. Two of the main tributaries (Khor Tagor and Khor Kajeer) are formed in these areas with large amounts of water. El Obeid is in the northern part and the amount of rainfall decreases from the South to the North. Guidelines from WMO (WMO, 1994) recommend a certain density of rainfall stations within a catchment to have representative measurements. For interior plains the recommendation is 5750 km^2 per station. For Khor Abu Habil this means that at least 6 stations would be preferable for such a large catchment. In this case, during the period when flow data is available, we only have rain records from 2 stations, which make the calibration of the model very uncertain. Local rainfall that increases the flow may not be registered by Rashad and El Obeid and the model is therefore difficult to calibrate.

A comparison between the two rainfall stations and the water flow at Abu Habil, Rashad is more representative. El Obeid shows opposite pattern. A year with higher flow has less rain in El Obeid and a year with low flow has high amounts of rainfall in El Obeid. Rashad, however, has rainfall in the month before and after the recordings of the water flow.

About 15 % of the annual rainfall shows no water flow in Abu Habil station. According to another study (Khor Abu Habil study, El Obeid March 2006), the Khor Abu Habil Mean annual run-off was approximately126 Mm^3 between 1978 and 1989. This value was, however, calculated for the entire Abu Habil catchment with an area of 36 800 km^2.

Dam Implement Unit (DIU) has started to conduct water flow measurements since 2010. The stations are placed close to where measurements have been done in the past. One of the flow monitoring stations are El Daland

Discharge data: Time series graphs of Abu Habil, and El Rahad (turda)are collected from different sources for the years 1976-1989 and the time series datais shown in Table 3.14. It can be observed that there is significant variability in discharge (in Mm^3) of Wadi Abu Habil, and El Rahad as the flow obtained from Abu Habil is being used by stakeholders for agriculture and other domestic purposes.

Table 3.14: Measured Runoff for Tributaries of Wadi Abu Habil (1976 – 1989)

Year	AbuHabil (Mm3/year)	ElRahad(turda) (Mm3/year)	AbuHabil total(Mm3/year)
1976		24517930	24517930
1977		17726841	17726841
1978	157678425	17962668	175641093
1979	61341480	13383279	74724759
1980	87868575	18898313	106766888
1981	197607483	29043792	226651275
1982	94474107	13241052	107715159
1983	181906299	32531510	214437809
1984	46990764	16477093	63467857
1985	293532336		293532336
1986	72944100		72944100
1987	33842250		33842250
1988	188223507		188223507
1989	104645016		104645016

Source: Abu Sidir, 2013

3.4.2 Watershed General Characteristics

A catchment is a distinct area of land with a common drainage system. A catchment includes both the water bodies that convey the water and the land surface from which water drains into these water bodies. The Abu Habil catchment refers to the total area drained by the main khor and its tributaries into the delta area.

The Khor Abu Habil catchment and its hydrological units have been topographically delineated from a Digital Elevation Model (DEM) (USGS, 2004) using GIS tools. The digital elevation model has a resolution of approximately 90 meters in length in Sudan. It should, however, be noted that the identification of catchments boundaries are extremely sensitive in a flat landscape where the altitude differences are small, due to the relatively crude resolution of the DEM. Hence, the estimated areas of the lower downstream sub catchments, and thereby also the total catchment area, are associated with some uncertainty. Ground controls of specific points of interest have been taken to minimize the uncertainty.

The sub-catchment division is based on the location of the major runoff stations as well as geographical features of the river sub-catchments. Catchment and sub-catchment boundaries have been defined from the digital elevation model, and the corresponding catchment areas calculated. The delineated sub-catchments are illustrated in Figure 3.5; their names and areas are presented in Table 3.15

The hydrological sub-catchments are used to describe the spatial distribution of water resources within the catchment.

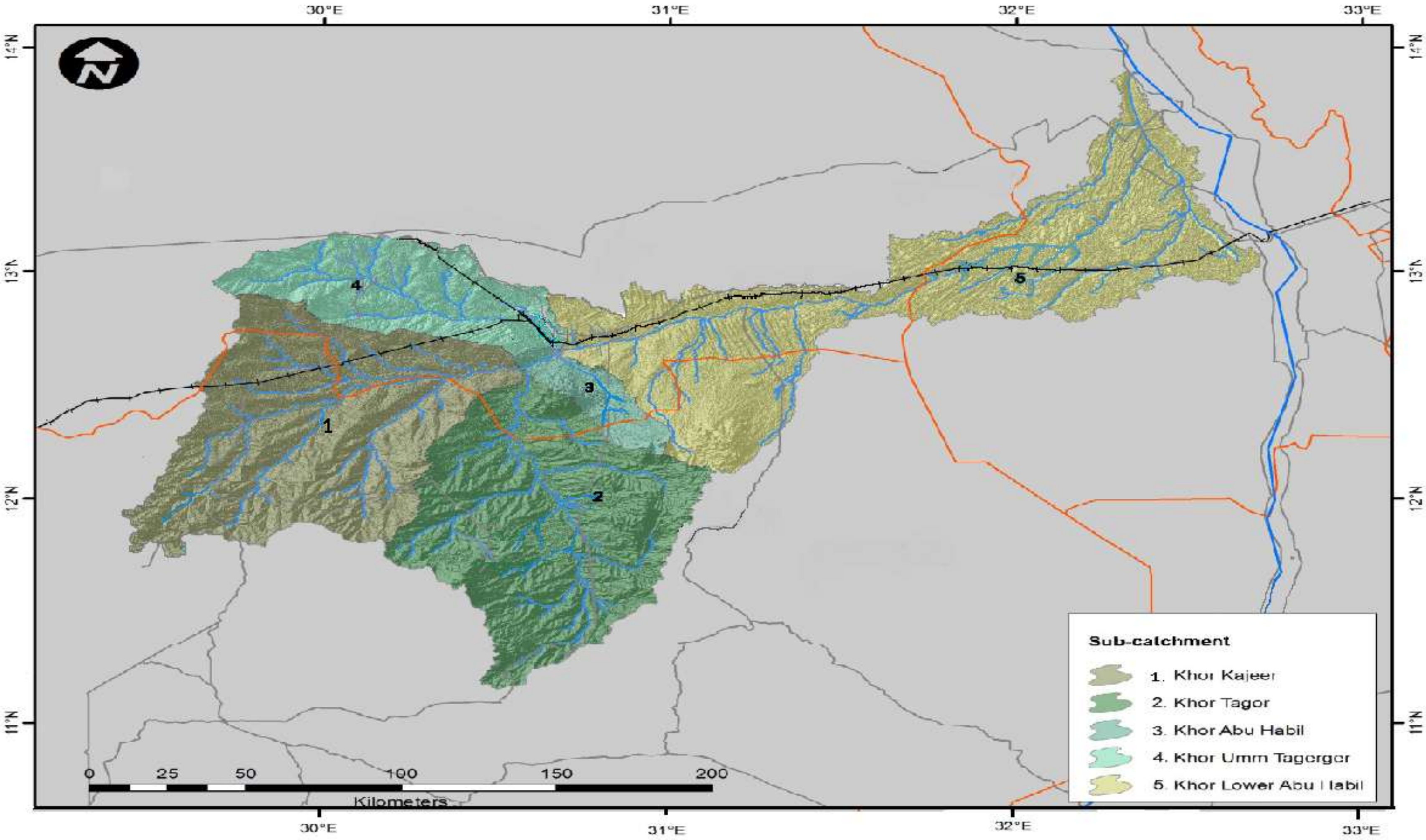


Figure 3.5: Khor Abu Habil catchments and its hydrological units Source SWECO, 2013

Table 3.15: Sub-Catchment areas within Khor Abu Habil

catctment NO.	Sub catchment NO.	Sub catchment Area (km2)
1	Khor Kajeer	8975
2	Khor Tagor	8703
3	Khor Umm Tagerger	3673
4	Khor Abu Habil	1050
5	Lower Khor Abu Habil	11669
Total		34070

3.4.3 NAM Model Input Data to Estimate Wadi Flow Rates

a- NAM Model Input Data: The values for the 9 parameters calibrated in the NAM model are shown in Table 3.16 the same parameters are the used for the other sub-catchments were there where no observed values. The rainfall stations and catchment areas are however different. (Mike Basin user manual,2014)

Table 3.16: The values of NAM parameters

Description	NAM- parameter	Value
Surface storage	Umax	12.5
Lower zone or root zone storage	Lmax	200
Overland flow	CQOF	0.4
Interflow	CKIF	650
Interflow and overland flow routing	CK1,2	48
Overland flow threshold	TOF	0.713
Interflow threshold	TIF	0.03
Groundwater recharge threshold	TG	0.6
Base flow	CKBF	3000

Source: SWECO, 2013

b- Evaporation and Evapotranspiration

Table 3.17 illustrates the ET values observed for different months at various regions of Abu Habil river basin.

Table 3.17: ET values observed for different months at Station No. 24 as example for various regions of Abu Habil basin.

Month	ET_o (mm/day)
Jan	3.54
Feb	4.14
Mar	5.15
Apr	4.21
May	5.75
Jun	6.09
Jul	5.45
Aug	4.76
Sep	4.62
Oct	3.79
Nov	3.35
Dec	1.73

Soure: CROPWAT

3.4.4 Input Data for Multi-criteria Analysis

Twelve possible water resources management scenarios were analyzed using Multi-criteria approach. These include: Base year (2012), decrease rain and increase Number (animal and population) and increase irrigation Area, Decrease rain and increase Number and construct Dam, Climate Change (Wet Rain fall), Climate Change (Dry Rain fall), Irrigation demand increase area (rainfall 2012), Two dams up stream and Tudra Dam, Erection of dam on Wadi (After Turda and before Semih), Impact of change demand (rainfall 2012), Impact of combined effect of change of(climate, area to irrigation) decrease rain and increase area, Combined increases number of population at(2030) and livestock(2030) and irrigation demand increases (Rain of 2030).

To study the impact of these management scenarios five water resource indicators were used namely: Flood Plain Inundation, Flow Variability, Wet Low Flow, Food production (ton/fed) and Food production (USD/fed).

The acceptable criteria limits chosen are given in table 3.18

Table3.18: The criteria acceptable limits

Weighting method		Ordinal Ranking	
		Acceptable limits	
Criteria	**Unit**	**Lower**	**Upper**
Flood Plain Inundation	m^3/s	15	89
Flow Variability	%	21	91
Wet Low Flow	m^3/s	8	77
Food production (ton/fed)	tan/fed	0	3.05
Food production (USD/fed)	USD/fed	0	2127

Reviews of criteria values generated from application of NB-DSS and used for scenario analysis are depicted in table3.19.

Table3.19: Criteria values generated from the Model to analyze the management Scenarios

Review Criteria Values					
Scenarios	m^3/s	%	m^3/s	ton/fed	USD ($)/fed
Unit	Flood Plain Inundation	Flow Variability	Wet Low Flow	Food production	Food production
Base year (2012)	062.500	085.000	059.500	003.050	2127.680
Climate Change Wet Rain fall	089.000	091.000	077.000	003.88	2706.900
Climate Change Dry Rain fall	016.000	021.000	008.000	000.000	000.000
Irrigation demand inc area (rainfall 2012)	057.500	067.000	047.000	003.220	2246.280
Two dams up stream and Torda Dam	062.000	069.000	053.500	002.450	1709.120
Erection of dam on Wadi(After tTorda and before Semih	077.000	078.000	063.500	002.890	2016.070
Impact of change demand (rainfall 012)	077.000	058.000	043.500	001.370	955.710
Impact of combined effect of change of (climate, area to irrigation) decrease rain and increase area	058.500	024.000	025.500	001.054	735.170
Combined inc Human population at(2030) and livestock (2030)	062.000	062.000	034.000	001.981	1381.950
Irrigation demand increase (Rain of 2030)	077.500	055.000	037.500	002.315	1614.980
decrease rain and Increase No (animal and population) and increase irrigation Area	027.000	024.000	019.000	000.378	263.760
decrease rain and Increase No(animal and population) and construct Dam	015.000	032.000	019.500	000.426	297.030

CHAPTER FURE
4. RESULTS AND DISCUSSIONS

4.1 General

From the data referred to in the previous Chapters a diagnostic analysis has been carried out through the water balance study, based on monthly data, considering the base conditions in 2012 and the no Action 2030 Scenarios. The Precipitation-Runoff-Model (NAM) model has been used to model the run-off in each sub-catchment and Mike Hydro has been used to model the water balance i.e. the balance between the supply and demands at each node in the catchment. Two initial situations were considered in the water balance model, one describing the present situation, (scenario 2012), and one describing a future situation, (scenario 2030), where an increased population poses higher water stress on the water resources.

The simulation describes:

1- Diagnostic analysis of the present hydraulic condition in the Abu Habil catchment, and is referred to as “Baseline 2012”;

2- A future scenario, “2030 Scenario”, has been set up as a reference scenario to determine the future water demand/deficit situation in the Abu Habil catchment.

3- Water balance Intervention studies: These expected management Scenario consisting mainly of the impacts of:

a- Climate change: increase (wet year) or decrease (dry year) in rain fall

b- Erecting new dams

c- Changes in water demand

d- Decrease in water runoff in Future (Future scenario, “2030 Scenario”, to determine the future water demand/supply situation)

e- Combined effects of changing demand and supply

4- Proposed improvement investment projects: Made for analysis and testing of interventions using different development scenarios and to identify a series of investment improvement projects of sufficient size to be analyzed in the water balance study.

3.3 Diagnostic analysis of base year Conditions (The Baseline (2012)

The main present water uses in the catchment are:

1-Rural water supply for basic needs (Villages of El Semaih, and El Hamra,) including commercial needs around: Rashad, El Rahad, , Tendalti, and El Dalang.

2-Livestock watering

3-Irrigated agriculture

This simulation describes the present condition in the Abu Habil catchment, and is referred to as "Baseline 2012". The water uses are represented at nodes and divided into categories for animal, human population, irrigated schemes, and added dams. This simulation is of great importance since it will highlight areas where water resources are scarce already today or stretched to the limit, indicating the need for improved water storage facilities and/or water distribution infrastructure.

4.2.1 Water Balance for each sub-catchment

The water balance analysis has been performed to investigate where water shortages occur in the Abu Habil catchment area and where improved water supply infrastructure would best serve the future water supply to the communities.

The NB-DSS software has been used to simulate the base year condition (2012), future scenario 2030 and the 2030 no action scenario. The model applies the NAM-model run-off results water uses have been identified and their corresponding water demand has been calculated as shown as part of the water balance in table 4.1.

Table 4.1: Catchment Water Balance

Water Resources Mm3/year	
Catchment(Node)	Annual Supply
Tagor	86.163
Khor Kajeer	72.8352
Lower Abu Habil	41.87246
Umm Tagrger & Turda	28.48536
Upper Abu Habil	16.10028

The results indicate that water communing from the river and water used in river and water need to complete demand in all catchment

Comparison of estimate runoff in each node or sub- catchment with that given by SWECO (2013) is depicted in table 4.2. From the table and using t-test there is no significant difference between the two estimates.

Table 4.2: Comparison of Flow with SWECO (2013) study with Present study

Sub- Catchment	SWECO study	Present study
	(Mm^3/year)	(Mm^3/year)
Tagor	80.09	86.16
Kajeer	41.16	72.84
Lower Abu Habil	44.02	41.87
Umm Tgerger	6.61	28.49
Upper Abu Habil	12.39	16.1

Note: t from table5% =2.776; t from table1%=2.132, t calculate 1.949

As expected, the water sources with the highest potential are the sub-catchments located in the southern part of the catchment, i.e., Khor Tagor, Khor Kajeer where the rainfall is highest and Lower water sources is Umm Tagerger that supplies the Turda followed by lower Abu Habil,. The sub-catchment with the lowest water production lies in the driest zone of rain fall (Upper Abu Habil and Umm Tagrger).

Measured and model estimated runoff values of Khor Abu Habil and its tributaries are given in figure 4.1.

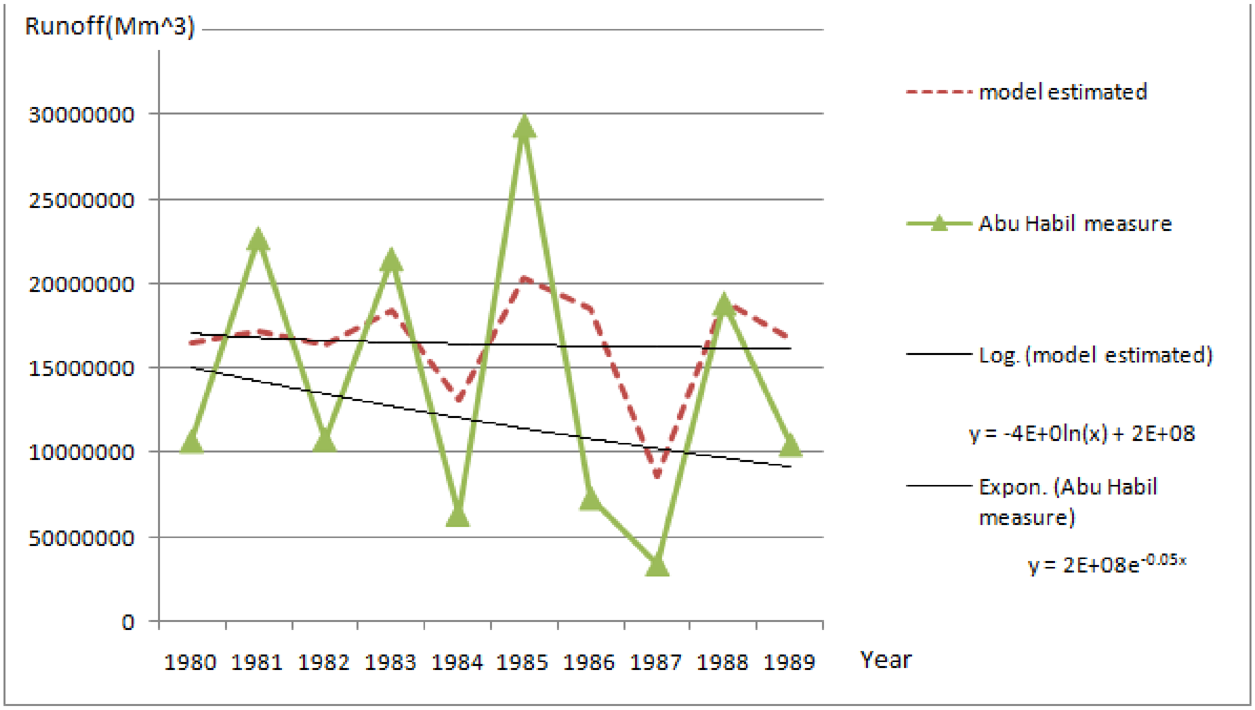


Figure 4.1: Estimating runoff over Abu Habil watershed using measured and model generated values

Comparison of measured and model estimated runoff values of Khor Abu Habil and its tributaries is given in figure4.2. The data given in the figure showsacceptable correlation coefficient (R2=0.6) which indicates agreement between the measured and model estimated runoff values. This result is in agreement with that reported by –IFAD (2000).

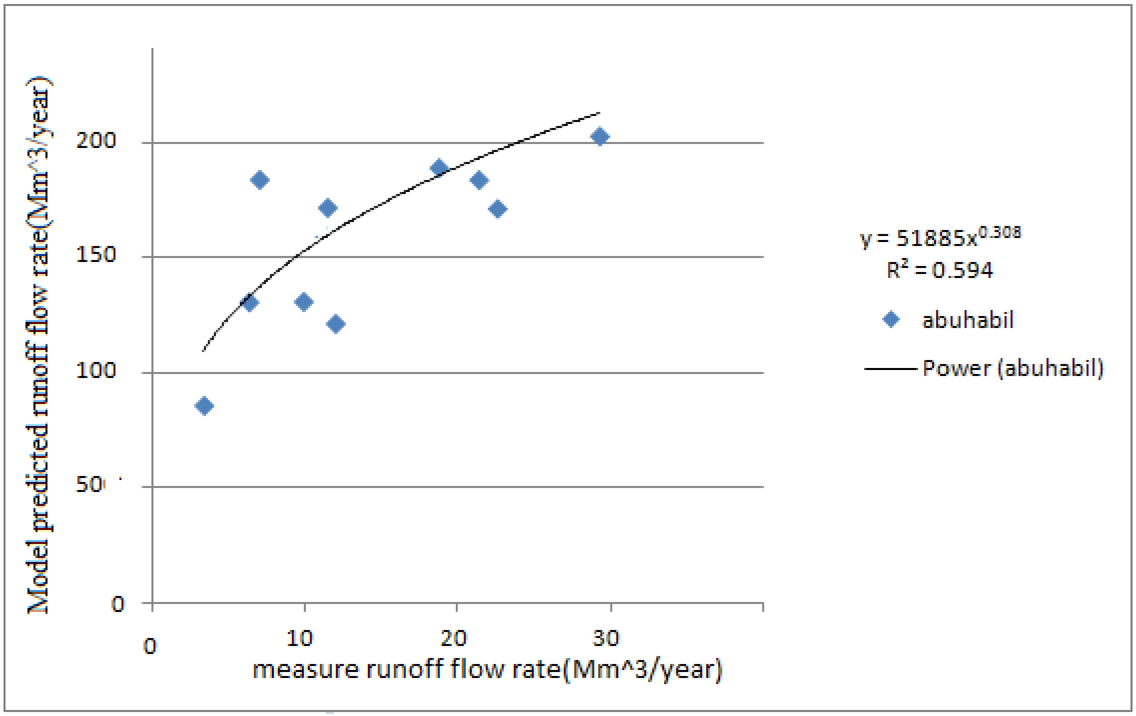


Figure 4.2: Comparison of measured and model estimated runoff values of Khor Abu Habil and its tributaries.

Comparisons of flow estimated by the NB-DSS (NAM module) for the five sub-catchments of Abu Habil are depicted in figure 4.3. The figure shows variability in the flow for each of the sub-catchments. Khor Kajeer has the highest variability, closely followed by Khor Tagor, while Abu Habil and Umm Tagerger are far more stable in their flows

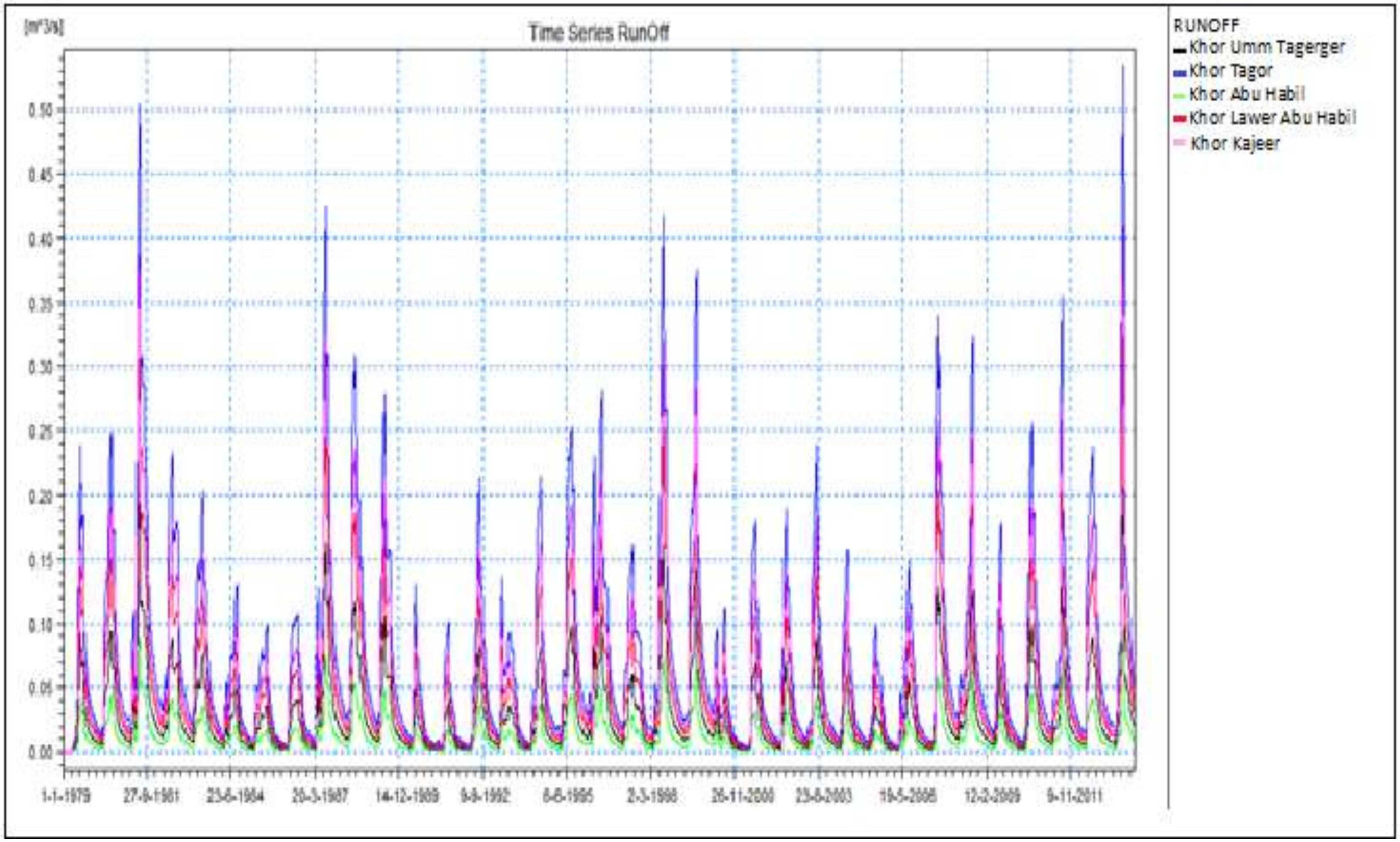


Figure 4.3: Run-off results for Abu Habil River Catchment for the period 1980-2012.

The overall demand by user type in the Wadi is given in table 4.3. The table indicates how the direct water demand will develop over the coming 20 years in comparison to the current situation. The increase in demand is significant and is mainly a consequence of the current plans to develop large-scale extensions of irrigation schemes and due to expected increase in population numbers. This will create a more water-stressed river system. It is also evident from the table that: irrigation is the largest water user followed by domestic (For Urban population and the lowest is livestock.

Table 4.3: Overall Current and future Water Demand by user type

User Type	Current Water Demand (Mm^3/year)(base year 2012)	Future Water Demand (Mm^3/year)(Expected year 2030)	difference %
Dams & Haffirs (For Rural population)	44000	54000	81
Irrigation	331.822	986.359	34
Domestic(For Urban population)	22.11	35.715	62
Livestock	7.955	13.942	57

Part of the water demand will be satisfied directly from the Abu Habil run-off if climate is in good condition, part of the demand will be satisfied from other indirect sources (ground water). The current major storage capacities of dams, haffirs and natural Turdas (Al Debaibat Dam, Tendalti Dam and the two Turdas of Rahad and Sherkela) are limited (44000Mm^3) and expected not to be sufficient to face future demand (54000 Mm^3) . Water scarcity and supply deficiency are major challenges and thus increasing storage and efficient allocation are priority tasks. Possible options to be studied in details is to erect new dams (Suggested locations are in Kajeer, Um Tagrgar and Tagor) pumping plants from ground water and Haffirs.

Water balance analysis for the base year (2012) for each sub-catchment is presented and given bellow:

I. Khor Kajeersub-basin

Khor Kajeer sub-basin has important urban and livestock water demands. The most important area is the city of Dalang, where the water demands are currently high and will further increase by year 2030. In addition, shortages are also registered for El Hamra and the livestock needs downstream.

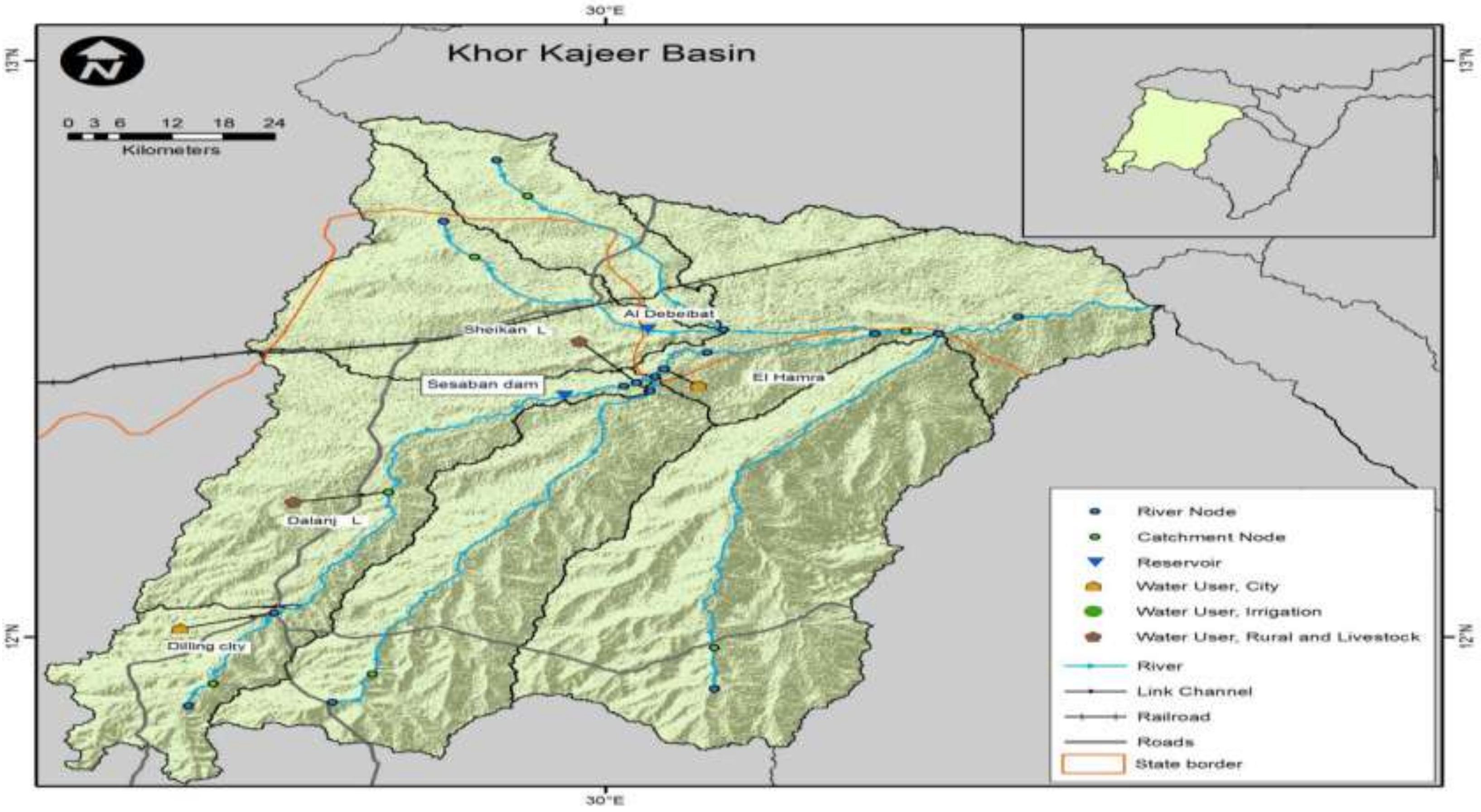


Figure 4.4: Khor Kajeer sub-basin

Source: SWECO, 2013

The water balance for the base year given in Table 4.4(according to Catchment or Node) and 4.5 (according to user) shows the Present Condition for the year of 2012, the results indicate an important water deficit that amounts to 31.6%, for the supply of water resources to the urban areas. Specifically, it can be mentioned that the City of Dalang and el Hamra village has a deficit of 66%, The livestock has no water deficit in wet months. Excess water

Table 4.4: Water balance for base year

Khor Kajeer Mm^3/year						
User	Annual Supply	Demand	Used	Deficit	Deficit %	Excess water
Overall Water Balance	72.835	8.163	5.578	2.585	31.669	0.112
Animal	0.035	0.035	0.035	0.000	0.000	1.000
Human	0.043	0.128	0.043	0.085	66.667	2.976
Dam	5.500	8.000	5.500	2.500	31.250	1.454

Table 4.5: Khor Kajeer Node Details) in base year

Khor Kajeer m^3/s						
User	Annual Supply	Demand	Used	Deficit	Deficit %	Excess water
Al Dalang Human	0.155	0.464	0.155	0.309	66.667	2.993
El Hamra Village	0.338	1.013	0.338	0.675	66.667	2.997
Al Debeibat Dam	34.722	46.296	34.722	11.574	25.000	1.333
Sesaban Dam	28.935	46.296	28.935	17.361	37.500	1.600
Animal	0.406	0.406	0.406	0.000	0.000	1.000

II. Khor Tagorsub-basin

Khor Tagor is the sub-basin where the major part of Khor Abu Habil run-off is produced and is therefore a strategic area to safeguard water supply not only within the proper sub-basin but also from a regional perspective to provide water to the urban areas downstream, Table 4.6 shows water balance for the base year and table 4.7 shows water user details.

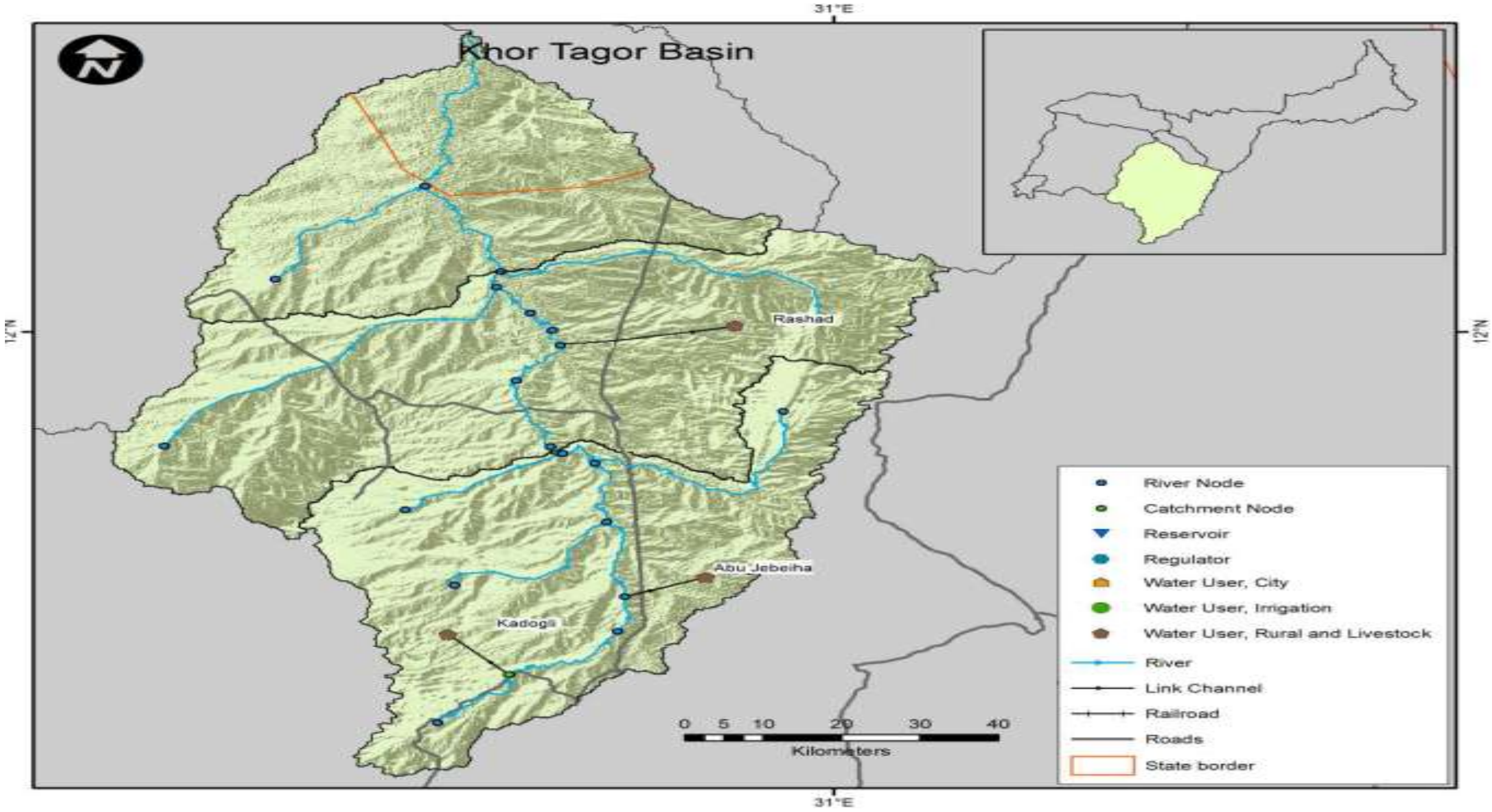


Figure 4.5: Khor Tagor sub-basin

Source: SWECO, 2013

Table 4.6: The water balance for the base year

Khor Tagor Mm^3/year						
User	Annual Supply	Demand	Used	Deficit	Deficit %	Excess water
Overall Water Balance	86.163	0.006	0.004	0.003	41.188	0.00
Animal	0.027	0.027	0.027	0.000	0.000	1.00
Human	0.015	0.044	0.015	0.029	66.667	2.93

Table 4.7: User (Node Details) in base year

Khor Tagor m^3/s						
User	Annual Supply	Demand	Used	Deficit	Deficit %	Excess water
Rashad human	0.121	0.363	0.121	0.242	66.667	3.00
Kadougli	0.011	0.033	0.011	0.022	66.667	3.00
Abu Jebeeha	0.038	0.113	0.038	0.075	66.667	2.97
Rashad livestock	0.315	0.315	0.315	0.000	0.000	1.00

From the table the water deficit related to the livestock remains constant over the period whereas the deficit related to the human user will correspond to 66% of its total water demand

III. Umm Tagrger Sub-basin

Major urban cities such as El Rahad are concentrated in the Um Tagerger sub-basin. The city with its substantial need for urban water supply,large uncertainties are associated with the water supply to this town that receives water from the El Rahad turda and reservoir of Ban Gadeed

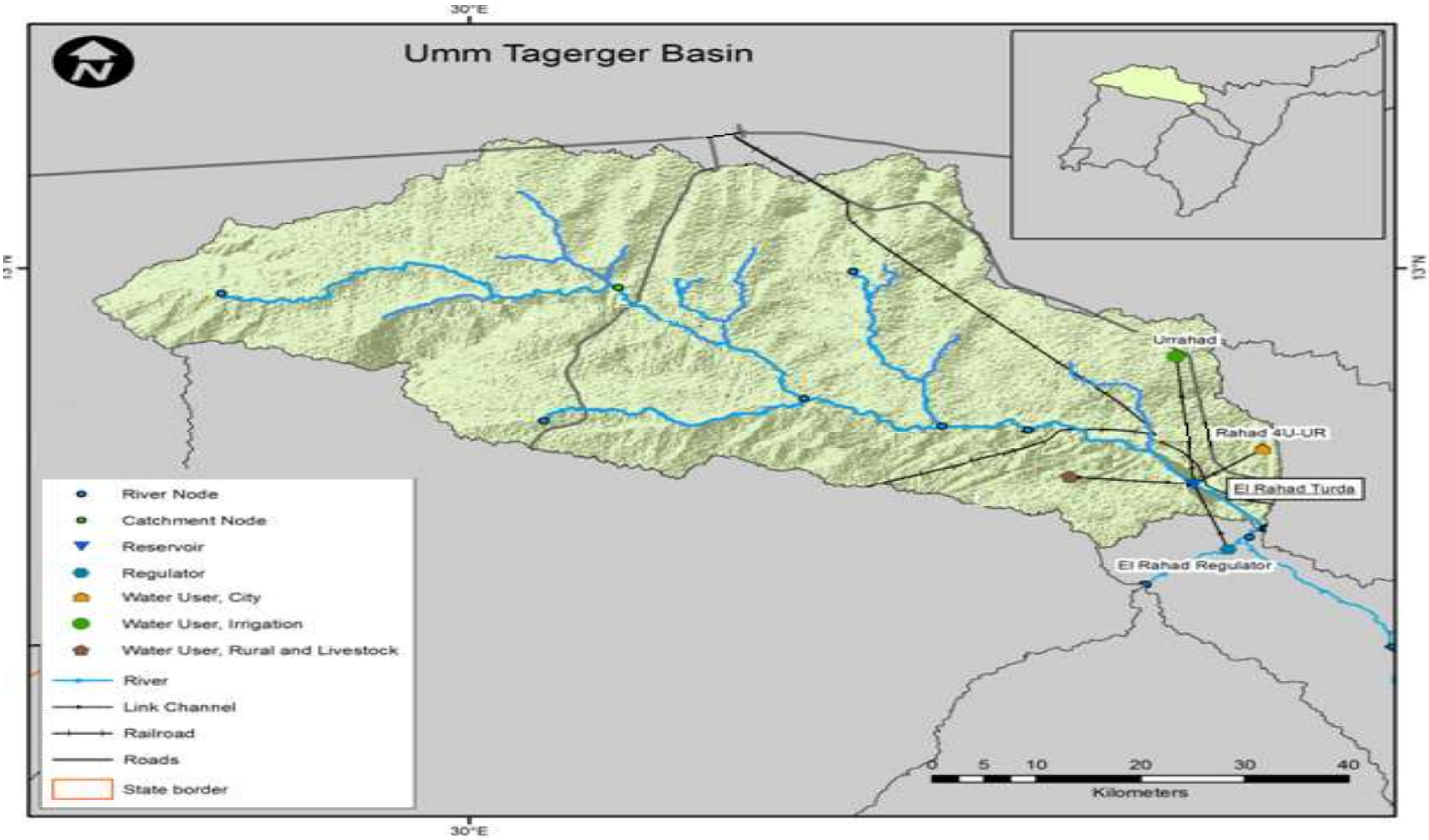


Figure 4.6: Khor Um Tagerger Sub-basin

Source: SWECO, 2013

Table 4.8: Khor Um Tagerger flow rate (Mm3/year)

Khor Um Tagerger (Mm^3/year)						
User	Annual Supply	Demand	Used	Deficit	Deficit %	Excess water
Overall Water Balance	28.4854	42.0875	31.4243	10.6632	25.3357	1.48
Dam	31.3952	42	31.3952	10.6048	25.2496	1.34
Human	0.0292	0.0875	0.0292	0.0583	66.6667	3.00

Table 4.9: Khor Um Tagergeruser (Node Details) in 2012

Khor Um Tagergrt (m^3/s)						
User	Annual Supply	Demand	Used	Deficit	Deficit %	Excess water
El Rahad turda	340.222	462.963	340.222	122.741	26.5121	1.36
Bangadeed	23.1481	23.1481	23.1481	0.000	0.000	1.00
El Rahad human	0.3376	1.0128	0.3376	0.6752	66.6667	3.00

It can see in table relative deficit in El Rahad Turda amont 26 %and El Rahad Town 66%

IV. Abu Habil sub-basin

Abu Habil Central is a smaller area between Khor Tagor and Lower Abu Habil southern part. This central area between regulator nodes is the so called Rahad regulator, which diverts water from Khor Tagor and Khor Kajeer into the Turda that is located in the Um Tagerger catchment (Figure 4.7).

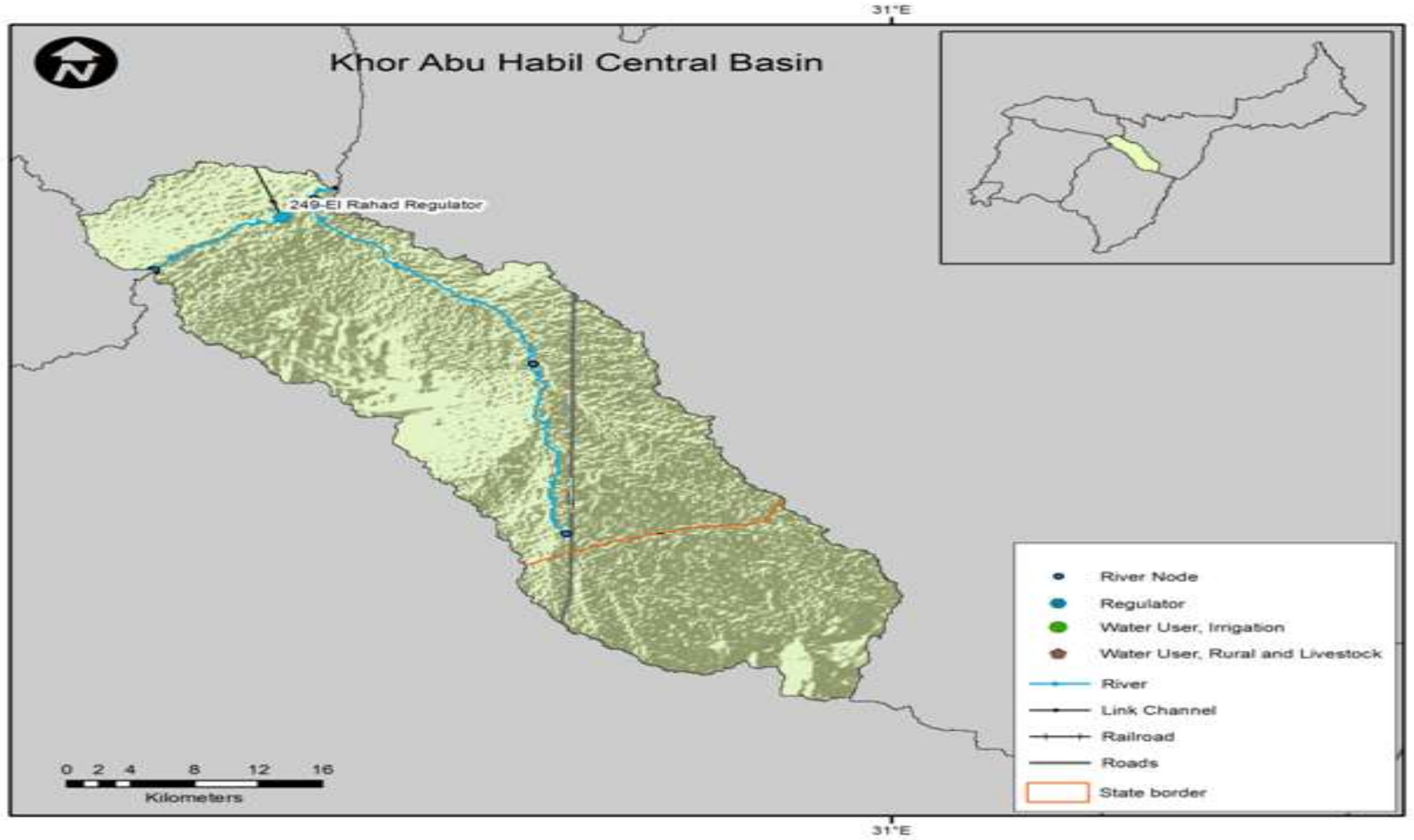


Figure 4.7: Khour Abu Habil Central Basin

Source SWECO, 2013

V. Lower Abu Habilsub-basin

Lower Abu Habil is an area where major centers are located, both urban and agricultural. The majority of the population is concentrated in this area. There are plans that account for increase in irrigable lands.

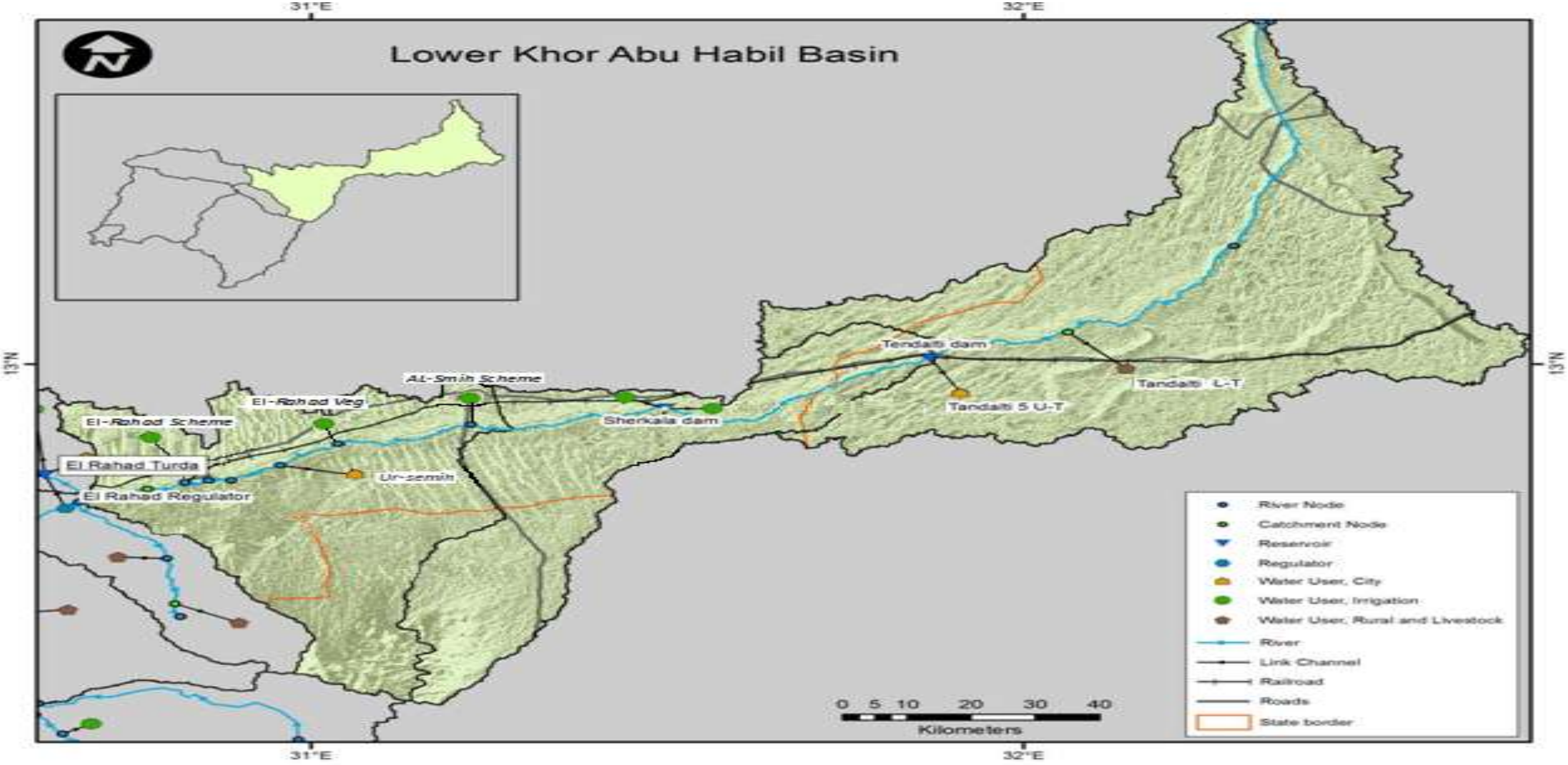


Figure 4.8: Lower Khor Abu Habil Sub-basin

Source: SWECO, 2013

Table 4.10: Lower Khor Abu Habil Flow Rate (Mm3/year)

lower Khor Abu Habil (Mm3/year)						
User	Annual Supply	Demand	Used	Deficit	Deficit %	Excess water
Overall Water Balance	41.873	4.976	4.782	0.194	3.898	0.12
Dam	4.000	4.000	4.000	0.000	0.000	1.00
Human	0.016	0.042	0.016	0.026	61.194	2.58
Animal	0.025	0.025	0.025	0.000	0.000	1.00
Scheme	0.741	0.909	0.741	0.168	18.511	1.23

Table 4.11: Lower Khor Abu Habil Catchment(Node Details)

lower Khor abu habil (m^3/s)						
User	Annual Supply	Demand	Used	Deficit	Deficit %	Excess water
Rahad	1.73	2.287	1.73	0.557	24.342	1.32
Vegetable	0.115	0.142	0.115	0.028	19.512	1.23
El Semeih	6.729	8.093	6.729	1.363	16.848	1.20
El Semeih Village	0.056	0.167	0.056	0.111	66.667	2.98
Tandalti human	0.133	0.319	0.133	0.186	58.333	2.40
Tandalti livestock	0.288	0.288	0.288	0.000	0.000	1.00
Tandalti dam	23.148	23.148	23.148	0.000	0.000	1.00
Sherkela Turda	23.148	23.148	23.148	0.000	0.000	1.00

From Table 4.11 it can be seen that the water deficit is large in El Semeih Village and Tandelti Town about 66 %, 58% respectively and the irrigation scheme deficit about 18%

4.2.2 Summary of Water Balance Analysis for the Base situation

The summary of the results of the water used as well as the water deficit for each node during the modeled period 1980-2012 is as follows: Khor Kajeer, Umm Tagrger .Tagoor, Abu Habil, Lower Abu Habil

Table 4.12: Water Resources Mm3/year

Catchment	Water Resources (Mm^3/year)					
	Annual Supply	Demand	Used	Deficit	Deficit %	Excess water
Khor Kajeer	72.835	8.163	5.578	2.585	31.669	0.11
Umm Tagrger & Turda	28.485	42.088	31.424	10.663	25.336	1.48
Tagoor	86.163	0.006	0.004	0.003	41.188	0.00
Lower Abu Habil	41.872	4.976	4.782	0.194	3.898	0.12
Abu Habil	16.1	-	-	-	-	0.00

In all areas, except Abu Habil Central, there is a water deficit in the baseline scenario (2012scenarios). The water deficit in Khor Kajeer is 31.6% and in Khor Tagor 41.1% and Um Tagerger 25.3% and in Lower Abu Habil 3.8% for the baseline scenario (2012 scenarios).

The overall water user for the baseline scenario is presented in table 4.13.

Table 4.13: Overall water user base Conditions (The Baseline (2012)

User	The Baseline (2012) m^3/s					
	Annual Supply	Demand	Used	Deficit	Deficit %	Excess water
Animal	1.009	1.009	0.603	0.406	40.260	1.00
Human	1.006	3.019	1.006	2.013	66.667	3.00
Irrigation	8.574	10.522	8.574	1.948	18.513	1.23
dawn strem	0.420	0.606	0.42	0.186	30.674	1.44

From the table it is evident that the human water user face high water deficit is all catchment (about 66%) because the water in Khor Abu Habil is seasonal.

At the end of this chapter the water balances for base year scenario is presented, which is a result of the analysis performed herein. It is noted that Khor Kajeer and Khor Tagor represents 66 % of the water production in the river catchment. The runoff, if efficiently managed, should be enough to cover the water demands that range between 44361.88 Mm^3 in the current scenario and 55036.02 Mm^3 in the year of 2030.

3.4 Future scenario (year 2030)

A future scenario, “2030 Scenario”, has been set up as predicted scenario to determine the future water demand -deficit situation in Abu Habil catchment if no change in runoff has taken place up to 2030 (base year runoff is assumed prevailing) which will also enable comparisons with other development scenarios. The input in this scenario is the same as used in Baseline 2012 and the change is in an estimation of the future water demand in every node after estimations of for example population growth, urbanization, new irrigation schemes etc. This scenario describes an imagined future situation where no actions have been taken to strengthen the water storage and regulating capacities in the area. The results highlight areas where water resources will be scarce under this (unfortunate) future scenario. A comparison with the “Baseline 2012” simulation identifies the areas with the highest incremental increase in the pressure on the scarce water resources, given today’s development plans up to 2030 fully implemented and the increased population. Together, the two simulations form a good basis for setting up future scenarios that are able to relieve the pressure by improving storage capacities and distribution networks at strategic locations.

The results presented are as follows:

Total demand volume: The annual average water demand in million cubic meters over the modeling period for each water demand node.

Total deficit volume: The annual average water deficit in million cubic meters over the modeling period for each water demand node.

Relative Water deficit: The ratio between the total water demand volume and the total deficit volume. The objective is to reach 0% water deficit for urban and livestock nodes and max 20% deficit for irrigation nodes.

The overall water balance future scenario 2030 scenario is presented in table 4.14

Table 4.14: The overall water balance future scenario 2030

Catchment	Water Resources (Mm^3/year)					
	Annual Supply	Demand	Used	Deficit	Deficit %	Excess water
Khor Kajeer	52.996	10.127	07.11	03.017	29.788	0.190
Tagoor	62.892	00.116	00.069	00.047	40.833	0.000
Umm Tagrger and Turda	23.561	42.141	29.238	12.903	30.618	1.790
Lower Abu Habil	38.471	05.651	05.215	00.436	07.722	0.150
Abu Habil	11.780	-	-	-	-	0.000

I. Sub-basin

1) Khor Kajeer

Table 4.15Shows details of analysis of future water balance (2030). The table indicates increases water demand and deficit in catchment

Comparison of existing situation (2012) and future scenario (2030) is shown in table4.16

The table indicates that change water in supply, demand and deficit in future.

Table 4.15: Analysis of future water balance (2030) for Khor Kajer

Khor Kajeer (Mm^3)						
User	Annual Supply	Demand	Used	Deficit	Deficit %	Excess water
Overall Water Balance	52.996	10.127	07.110	3.017	29.788	0.19
Animal	00.035	00.035	00.035	0.000	00.000	1.00
Human	00.084	00.092	00.028	0.063	69.112	1.10
Dam	07.047	10.000	07.047	2.953	29.532	1.42

Show in table hay water deficient for human in future scenario about 69%

Table 4.16: Comparison of Overall water balance for existing situation (2012) and future scenario (2030)

Khor Kajeer (Mm^3)						
Case	Annual Supply	Demand	Used	Deficit	Deficit %	Excess water
existing situation (2012)	72.835	8.163	5.578	2.585	31.669	0.112
future scenario (2030)	52.996	10.127	7.11	3.017	29.788	0.191

2) Khor Tagor

Table 4.17: Overall water balance for Khor Tagor

Khor Tagor Mm^3/year						
User (Node)	Annual Supply	Demand	Used	Deficit	Deficit %	Excess water
Overall Water Balance	62.891	0.1161	0.0687	0.047	40.832	0.002
Animal	0.045	0.045	0.045	0.000	0.000	1.000
Human	0.0237	0.0711	0.0237	0.047	66.667	3.000

Table 4.18 Comparison of Overall water balance for existing situation (2012) and future scenario (2030) in Khor Tagor

Khor Tagor Mm^3/year						
Case	Annual Supply	Demand	Used	Deficit	Deficit %	Excess water
existing situation (2012)	86.163	0.006	0.004	0.003	41.188	0.000
future scenario (2030)	62.8918	0.1161	0.0687	0.0474	40.8328	0.002

3) Khor Um Tagerger

Table 4.19 Overall water balance for Khor Umm Tagerger

Khor Um Tagerger Mm^3/year						
User	Annual Supply	Demand	Used	Deficit	Deficit %	Excess water
Overall Water Balance	23.561	42.141	29.238	12.903	30.618	1.789
Dam	29.191	42	29.191	12.809	30.497	1.439
Human	0.047	0.141	0.047	0.094	66.667	3.000

The dam water deficit increase from 2012 to 30.6%

Table 4.20: Comparison of Overall water balance for existing situation (2012) and future scenario (2030) in Khor Um Tagerger

Khor Um Tagerger Mm^3/year						
Case	Annual Supply	Demand	Used	Deficit	Deficit %	Excess water
existing situation (2012)	28.4854	42.0875	31.4243	10.6632	25.3357	1.478
future scenario (2030)	23.561	42.141	29.238	12.903	30.618	1.789

4) Lower Khor Abu Habil

Table 4.21: Overall water balance for lawer Abu Hbil

lower Khor Abu Habil Mm^3/year						
User	Annual Supply	Demand	Used	Deficit	Deficit %	Excess water
Overall Water Balance	38.471	5.651	5.215	0.436	7.722	0.147
Dam	4.000	4.000	4.000	0.000	0.000	1.000
Human	0.026	0.064	0.026	0.038	59.217	2.462
Animal	0.046	0.046	0.046	0.000	0.000	1.000
Scheme	1.143	1.541	1.143	0.398	25.835	1.348

Increases irrigation scheme water deficit from base year (2012)18% to 25.8% in future scenario.

Table 4.22 Comparison of Overall water balance for existing situation (2012) and future scenario (2030) in Lowe Abu Habil

lower Khor Abu Habil Mm^3/year						
Case	Annual Supply	Demand	Used	Deficit	Deficit %	Excess water
existing situation (2012)	41.8725	4.9759	4.7819	0.194	3.8982	0.119
future scenario (2030)	38.471	5.651	5.215	0.436	7.722	0.147

II. Users

Details of water balance for each user in Abu habil catchment is show in the following tables

a) Khor Kajeer Sub-basin

Table 4.23: User (Node Details) for 2030 year in Khor Kajeer

Khor Kajeer(m^3/s)						
User	Annual Supply	Demand	Used	Deficit	Deficit %	Excess water
Al Dalang human	0.250	0.750	0.250	0.500	66.667	3.000
El Hamra Village	0.720	0.311	0.078	0.234	75.000	0.430
Al Debeibat dam	31.773	46.296	31.773	14.523	31.37	1.450
Sesaban dam	49.787	69.444	49.787	19.657	28.307	1.390
Animal	0.720	0.720	0.720	0.000	0.000	1.000

b) Khor Tagor Sub-basin

Table 4.24: User (Node Details) for 2030 year in Khor Tagor

Khor Tagor m^3/s						
User	Annual Supply	Demand	Used	Deficit	Deficit %	Excess water
Rashad human	0.195	0.586	0.195	0.391	66.667	3.000
Kadougli	0.018	0.054	0.018	0.036	66.667	3.000
Abu Jebeeha	0.061	0.183	0.061	0.122	66.667	3.000
Rashad livestock	0.521	0.521	0.521	0.000	0.000	1.000

c) Khor Umm Tagergr Sub-basin

Table 4.25: User (Node Details) for 2030 year in Khor Umm Tagergr

Khor UmmTagergr m^3/s						
User	Annual Supply	Demand	Used	Deficit	Deficit %	Excess water
El Rahad turda	320.502	462.963	320.502	142.461	30.772	1.44
Bangadeed	17.361	23.148	17.361	5.787	25.000	1.33
El Rahad human	0.545	1.636	0.545	1.091	66.667	3.00

d) Lower Khor Abu habil Sub-basin

Table 4.26: User (Node Details) for 2030 year in Lower Khor Abu habil

Lower Khor Abu habil m3/s						
User	Annual Supply	Demand	Used	Deficit	Deficit %	Excess water
Rahad Scheme	5.029	6.646	5.029	1.618	24.342	1.320
Vegetable Scheme	0.471	0.585	0.471	0.114	19.512	1.240
El Semeih Scheme	7.731	10.608	7.731	2.877	27.12	1.370
El Semeih Village	0.090	0.269	0.09	0.179	66.667	2.990
Tandalti human	0.215	0.477	0.215	0.262	55.012	2.220
Tandalti livestock	0.528	0.528	0.528	0.000	0.000	1.000
Tandalti dam	23.148	23.148	23.148	0.000	0.000	1.000
Sherkela Turda	23.148	23.148	23.148	0.000	0.000	1.000

4.4 Outcomes of Water Balance Analysis for Future Situation

Water deficit in the present condition (2012) and future scenarios (2030)is given in Table 4.3. The major shortages are registered in Um Tagerger where annual water deficits reach 10.7 Mm^3/year for the present conditions (2012) and increases to 12.9 Mm^3/year in future scenarios (2030). This is followed by Khor Kajeer which is 2.6 Mm^3 and goes up in future to 3.0 Mm^3. The water deficit in the whole basin increases in future from a value of 13.5 Mm^3 to 16.4 Mm^3.However minimum deficient in the present and future cases in Lower Abu Habil.

Table 4.27: Summary Wadi Overall water balance and deficits 2012 and future 2030 Scenario (at sub-catchment level)

Sub-Catchment	Khor Kajeer	Khor Tagor	Umm Tagerger	Abu Habil	Lower Abu Habil	Total
Total Runoff 2012 (Mm3/year)	72.835	86.163	28.485	16.100	41.873	245.460
Total Runoff 2030 (Mm3/year)	52.996	62.892	23.561	11.780	38.471	189.700
Water deficit 2012(Mm3/year)	02.585	00.003	10.6632	-	00.194	013.450
Water deficit 2030(Mm3/year)	03.017	00.047	12.903	-	00.436	016.400

4.5 Impacts of possible management Scenarios on water Resources

This expected management Scenarios are related to the balance water resources and their utilization: The expected management Scenario consisting mainly of the impacts of:

- Climate change: increase (wet year) or decrease (dry year) in rain fall
- Erecting new dams
- Changes in water demand
- Decrease in water runoff in Future (Future scenario, “2030 Scenario”, to determine the future water demand/supply situation)
- Combined effects of changing demand and supply
- Climate change: Rain fall increase (wet year) and Rain decrease (dry year)

Evaluation of impacts of Climate change with respect to the current situation (2012) and future (2030) is made in reference to each water resource user including: animal, human, irrigation scheme and Tandalti dawn stream users

1- Climate change impact on animal, human, irrigation scheme and Tandalti Downstream users based on the current situation

a- Climate change impact on Animal for wet and dry year based on the current situation

Table 4.28 indicates that the water deficient for animal demand is low in dry year (22%) and the deficient prevails usually during rain fall months. However, possible solution is to utilize ground water or let the animal travel out of the project area to southern direction were more rain fall is likely to prevail.

Table 4.28: Climate change impact on Animal for wet and dry year

Impact of Climate change						
Scenarios	Animal(m^3/s)					
	Annual Supply	Demand	Used	Deficit	Deficit %	Excess water
Base(2012)	1.01	1.01	1.01	0.00	0.00	1.00
Climate change (Rain fall)Wet year	1.01	1.01	1.01	0.00	0.00	1.00
Climate change (Rain fall)Dry year	0.69	1.01	0.79	0.22	21.53	1.46

b- Climate change impact on human domestic uses for wet and dry year based on the base situation

As shown in Table 4.29 water deficit is not high and same as that of the base demand in dry year (67.9 %).This because human is always giving first priority compared to other uses (e.g. irrigation).

Table 4.29: Climate change impact on human domestic uses for wet and dry year

Impact of Climate change						
Senarios	Human(m^3/s)					
	Annual Supply	Demand	Used	Deficit	Deficit %	Excess water
Base(2012)	1.006	3.019	1.006	2.013	66.667	3.00
Climate change (Rain fall)Wet year	1.006	3.019	1.006	2.013	66.667	3.00
Climate change (Rain fall)Dry year	0.979	3.019	0.979	2.041	67.899	3.09

c- Climate change impact on irrigation scheme for wet and dry year based on the base situation.

It is evident from table 4.30 that in dry year irrigation schemesare expected to face difficult situation and cultivation will not be possible all together (100% deficient).

Table 4.30: Climate change impact on irrigation scheme for wet and dry year

Impact of Climate change						
Scenarios	Irrigation Schemes(m^3/s)					
	Annual Supply	Demand	Used	Deficit	Deficit %	Excess water
Base(2012)	8.574	10.522	8.574	1.948	18.513	1.23
Climate change (Rain fall)Wet year	8.574	10.522	8.574	1.948	18.513	1.23
Climate change (Rain fall)Dry year	0.000	10.522	0.000	10.522	100.000	0.00

d- Climate change impact on Tandalti dawn stream users for wet and dry year based on the base situation.

It is given in table 4.31 that the dawn streams users of Tandalti shall face sever water shortage in dry year (83%)

Table 4.31: Climate change impact on Tandalti dawn stream users for wet and dry year

Impact of Climate change						
Scenarios	Tandalti (dawn stream User)m^3/s					
	Annual Supply	Demand	Used	Deficit	Deficit %	Excess water
Base(2012)	0.420	0.606	0.420	0.186	30.674	1.44
Climate change (Rain fall)Wet year	0.447	0.606	0.447	0.159	26.292	1.36
Climate change (Rain fall)Dry year	0.098	0.606	0.098	0.508	83.764	6.16

However for all of the above cases during wet years no water shortage is expected for all cases including even the dawn stream users

2- Erecting new dams compared to the base year

I. Erecting new dams for Animal

Erecting a dam between El Semeih and Rahad result in small deficient (7%) while erection of the other two dams (Um Tagrger and Tagoor Dams) solve the problem and no water shortage is expected (table 32).

Table 4.32: Impact of erecting new dams for Animal

Erection of dam						
	Animal(m^3/s)					
Scenarios	Annual Supply	Demand	Used	Deficit	Deficit %	Excess water
Base(2012)	1.009	1.009	1.009	0.000	0.000	1.00
Erection of dam On Wadi (After Turda and before Semaeih)	0.937	1.009	0.937	0.072	7.125	1.08
Two Dams at Up stream and Torda Dam (Up stram)	1.009	1.009	1.009	0.000	0.000	1.00

II. Erecting new dams for human

As given in table 4.33 Erecting a dam between El Semeih and Rahad result in a deficient equal to that of the base year(76.6%) while erection of the other two dams (Um Tagrger and Tagoor Dams) decrease water shortage by 10 %.

Table 4.33 Impact of erecting new dams for human

Erection of dam						
Scenarios	Human(m^3/s)					
	Annual Supply	Demand	Used	Deficit	Deficit %	Excess water
Base(2012)	1.006	3.019	1.006	2.013	66.667	3.00
Erection of dam On Wadi (After Turda and before Semaeih)	1.006	3.019	1.006	2.013	66.667	3.00
Two Dams at Up stream and Torda Dam (Up stram)	1.275	3.019	1.275	1.744	57.760	2.37

III. Erecting new dams for irrigation scheme

As given in table 4.34erecting a dam between El Semeih and Rahad or the other two dams (Um Tagrger and Tagoor Dams) decrease water shortage slightly (by 2 to 5%).

Table 4.34: Impact of erecting new dams for irrigation scheme

Erection of dam						
Scenarios	Irrigation Schemes (m^3/s)					
	Annual Supply	Demand	Used	Deficit	Deficit %	Excess water
Base(2012)	8.574	10.522	8.574	1.948	18.513	1.23
Erection of dam On Wadi (After Turda and before Semaeih)	8.747	10.522	8.747	1.775	16.874	1.20
Two Dams at Up stream and Torda Dam (Up stram)	9.102	10.522	9.102	1.420	13.494	1.16

IV. Erecting new dams for Tandalti dawn stream User

As given in table 4.35Erecting a dam between El Semeih and Rahad (relative deficit of 38%) while the other two dams (UmTagrger and Tagoor Dams) do not improve water shortage at all.

Table 4.35: Impact of erecting new dams for Tandalti downstream User

Erection of dam						
Scenarios	Tandalti (dawn stream User)m^3/s					
	Annual Supply	Demand	Used	Deficit	Deficit %	Excess water
Base(2012)	0.420	0.606	0.420	0.186	30.674	1.44
Erection of dam On Wadi (After Turda and before Semaeih)	0.375	0.606	0.375	0.231	38.146	1.62
Two Dams at Up stream and Torda Dam (Up stram)	0.420	0.606	0.420	0.186	30.674	1.44

III. Changes in water demand compared to the base year

i. Changes in water demand Animal

See in table 4.36increases water deficit to 17.6% in change water demand for population and live stock and 18.5% deficits in increase water demand for scheme.

Table 4.36: Changes in water demand for Animal

Impact of change demand(rain fall 2012)						
Scenarios	Animal(m^3/s)					
	Annual Supply	Demand	Used	Deficit	Deficit %	Excess water
Base(2012)	1.009	1.009	1.009	0.000	0.000	1.00
Impact of change demand (rain fall 2012) Population Increase No. and Live stock inc No.	1.457	1.768	1.457	0.312	17.638	1.21
Irrigation demand increase area (Rain of 2012)	1.440	1.768	1.440	0.327	18.515	1.23

ii. Changes in water demand for human

As given in table 4.37 impact of change demand (increase no of population and livestock) water deficit is incasing to 68.3% and 69.2 in increase water demand for scheme.

Table 4.37: Changes in water demand for human

Impact of change demand (rain fall 2012)						
Scenarios	Human(m^3/s)					
	Annual Supply	Demand	Used	Deficit	Deficit %	Excess water
Base(2012)	1.006	3.019	1.006	2.013	66.667	3.00
Impact of change demand (rain fall 2012) Population Increase No. and Live stock inc No.	1.126	3.553	1.126	2.427	68.305	3.15
Irrigation demand increase area (Rain of 2012)	1.092	3.553	1.092	2.461	69.263	3.25

iii. Changes in water demand for irrigation scheme

It is given in table 4.38 increase deficit to 32.6% from change demand (increase NO. of population and livestock) scenario and increase water demand for scheme to 41.4%

Table 4.38: Changes in water demand for irrigation scheme

Impact of change demand(rain fall 2012)						
Scenarios	Irrigation Schemes (m^3/s)					
	Annual Supply	Demand	Used	Deficit	Deficit %	Excess water
Base(2012)	8.574	10.522	8.574	1.948	18.513	1.23
Impact of change demand (rain fall 2012) Population Increase No. and Live stock inc No.	12.023	17.839	12.020	5.819	32.622	1.48
Irrigation demand increase area (Rain of 2012)	10.458	17.839	10.458	7.382	41.379	1.71

iv. Changes in water demand for Tandalti downstream User

See in table 4.39 scenarios of change water demand (increase NO. of population and livestock) and increase water demand for scheme the deficit is very hay from base yare to 48.5%, 53.9%.

Table 4.39: Changes in water demand for Tandalti downstream User

Impact of change demand (rain fall 2012)						
Scenarios	Tandalti (dawn stream User)m^3/s					
	Annual Supply	Demand	Used	Deficit	Deficit %	Excess water
Base(2012)	0.420	0.606	0.420	0.186	30.674	1.44
Impact of change demand (rain fall 2012) Population Increase No. and Live stock inc No.	1.078	2.098	1.078	1.020	48.598	1.95
Irrigation demand increase area (Rain of 2012)	0.967	2.098	0.967	1.131	53.916	2.17

IV. Decrease in water runoff in Future (Future scenario, “2030 Scenario”, to determine the future water demand-supply situation)

a) future scenario for Animal

In table 4.40 the water deficit for animal in future scenarios increases from base year to 17.6%

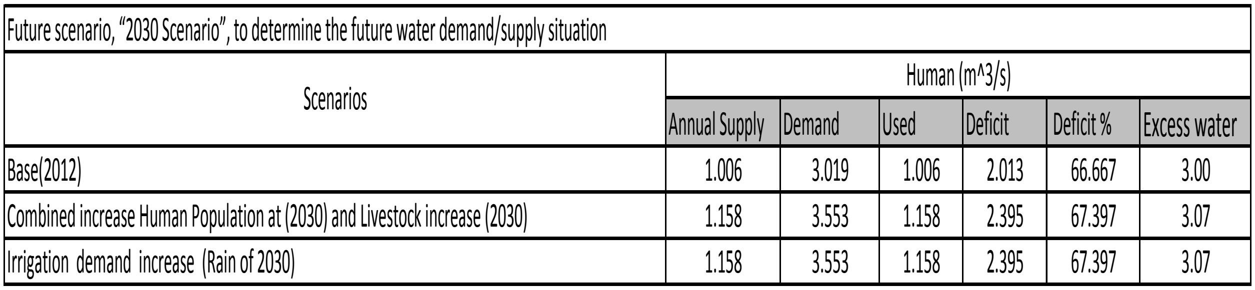
Table 4.40: Future scenario for Animal

Future scenario, “2030 Scenario”, to determine the future water demand/supply situation						
Scenarios	Animal(m^3/s)					
	Annual Supply	Demand	Used	Deficit	Deficit %	Excess water
Base(2012)	1.009	1.009	1.009	0.000	0.000	1.00
Combined increase Human Population at (2030) and Livestock increase (2030)	1.457	1.768	1.457	0.312	17.638	1.21
Irrigation demand increase (Rain of 2030)	1.457	1.768	1.457	0.312	17.638	1.21

b) Future scenario for Human

The water deficit in table (4.41) for human in future scenarios 67.39% and this deficit it not increases if irrigation scheme area increases because the borty for human

Table 4.41: Future scenario for Human

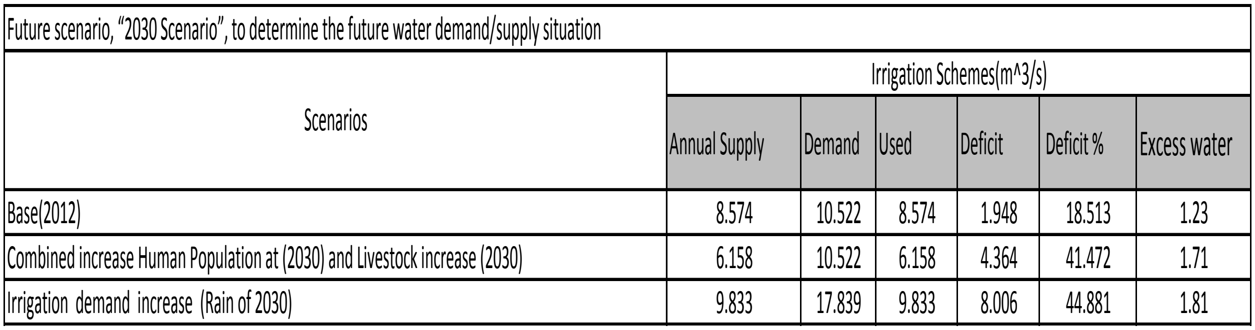


Future scenario, "2030 Scenario", to determine the future water demand/supply situation						
Scenarios	Human (m^3/s)					
	Annual Supply	Demand	Used	Deficit	Deficit %	Excess water
Base(2012)	1.006	3.019	1.006	2.013	66.667	3.00
Combined increase Human Population at (2030) and Livestock increase (2030)	1.158	3.553	1.158	2.395	67.397	3.07
Irrigation demand increase (Rain of 2030)	1.158	3.553	1.158	2.395	67.397	3.07

c) Future scenario for Irrigation

The water deficit in table (4.42) future scenario for irrigation scheme is 41.47% from base scenario and he is increase if scheme area increase to 44.8%

Table 4.42: Future scenario for Irrigation

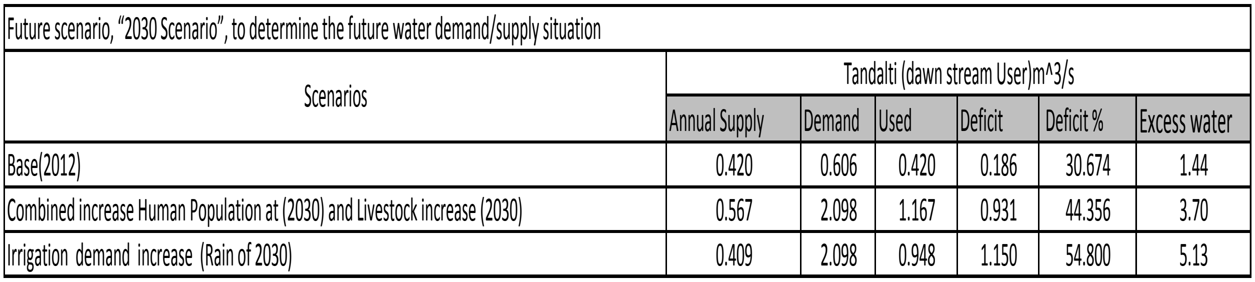


Future scenario, "2030 Scenario", to determine the future water demand/supply situation						
Scenarios	Irrigation Schemes(m^3/s)					
	Annual Supply	Demand	Used	Deficit	Deficit %	Excess water
Base(2012)	8.574	10.522	8.574	1.948	18.513	1.23
Combined increase Human Population at (2030) and Livestock increase (2030)	6.158	10.522	6.158	4.364	41.472	1.71
Irrigation demand increase (Rain of 2030)	9.833	17.839	9.833	8.006	44.881	1.81

d) Future scenario for Tandalti downstream User

In table 4.43 the water deficit in Future scenario for Tandalti downstream User is 44.35% and is rise to 54.8% if increase irrigation scheme area

Table 4.43: Future scenario for Tandalti downstream User



Future scenario, "2030 Scenario", to determine the future water demand/supply situation						
Scenarios	Tandalti (dawn stream User)m^3/s					
	Annual Supply	Demand	Used	Deficit	Deficit %	Excess water
Base(2012)	0.420	0.606	0.420	0.186	30.674	1.44
Combined increase Human Population at (2030) and Livestock increase (2030)	0.567	2.098	1.167	0.931	44.356	3.70
Irrigation demand increase (Rain of 2030)	0.409	2.098	0.948	1.150	54.800	5.13

V. Combined effects of changing demand and supply

a) Combined effects of changing demand and supply for Animal

Table 4.44: Combined effects of changing demand and supply for Animal

Impact of combined effect						
Scenarios	Animal(m^3/s)					
	Annual Supply	Demand	Used	Deficit	Deficit %	Excess water
Base(2012)	1.009	1.009	1.009	0.000	0.000	1.00
Impact of combined effect of change of(climate, area to irrigate) decrease rain and increase area	0.865	1.009	0.865	0.144	14.249	1.17
Impact of combined effect of change of(climate, population , live stock) decrease rain and increase No	1.309	1.768	1.309	0.459	25.978	1.35
Decrease rain, increase No and construct Dam On Wadi	1.258	1.768	1.258	0.512	28.947	1.41
Decrease rain, increase No and construct Dam 2- Dams and Torda Dam	1.236	1.768	1.236	0.533	30.150	1.43
Decrease rain and increase No (animal and population) and increase irrigation area	1.299	1.768	1.299	0.469	26.535	1.36
Decrease rain and increase No (animal and population) and increase irrigation area and construct Dam On Wadi	1.236	1.768	1.236	0.533	30.120	1.43
Decrease rain and increase No (animal and population) and increase irrigation area and construct Dam 2- Dams and Torda Dam	1.195	1.768	1.195	0.573	32.402	1.48

b) Combined effects of changing demand and supply Human

Table 4.45: Combined effects of changing demand and supply Human

Impact of combined effect						
Scenarios	Human(m^3/s)					
	Annual Supply	Demand	Used	Deficit	Deficit %	Excess water
Base(2012)	1.006	3.019	1.006	2.013	66.667	3.00
Impact of combined effect of change of(climate, area to irrigate) decrease rain and increase area	0.988	3.019	0.988	2.031	67.253	3.06
Impact of combined effect of change of(climate, population , live stock) decrease rain and increase No	1.079	3.553	1.079	2.475	69.649	3.29
Decrease rain, increase No and construct Dam On Wadi	1.059	3.553	1.059	2.494	70.201	3.35
Decrease rain, increase No and construct Dam 2- Dams and Torda Dam	1.095	3.553	1.095	2.458	69.179	3.24
Decrease rain and increase No (animal and population) and increase irrigation area	1.058	3.553	1.058	2.495	70.212	3.36
Decrease rain and increase No (animal and population) and increase irrigation area and construct Dam On Wadi	1.027	3.553	1.027	2.526	71.101	3.46
Decrease rain and increase No (animal and population) and increase irrigation area and construct Dam 2- Dams and Torda Dam	1.014	3.553	1.014	2.539	71.457	3.50

c) Combined effects of changing demand and supply Irrigation scheme

Table 4.46: Combined effects of changing demand and supply Irrigation scheme

Impact of combined effect						
Scenarios	Irrigation Schemes(m^3/s)					
	Annual Supply	Demand	Used	Deficit	Deficit %	Excess water
Base(2012)	8.574	10.522	8.574	1.948	18.513	1.23
Impact of combined effect of change of(climate, area to irrigate) decrease rain and increase area	10.133	17.839	10.133	7.706	43.199	1.76
Impact of combined effect of change of(climate, population , live stock) decrease rain and increase No	6.117	10.522	6.117	4.405	41.861	1.72
Decrease rain, increase No and construct Dam On Wadi	7.103	10.522	7.103	3.420	32.500	1.48
Decrease rain, increase No and construct Dam 2- Dams and Torda Dam	5.574	10.522	5.574	4.948	47.026	1.89
Decrease rain and increase No (animal and population) and increase irrigation area	9.263	17.839	9.263	8.577	48.077	1.93
Decrease rain and increase No (animal and population) and increase irrigation area and construct Dam On Wadi	11.720	17.839	11.720	6.119	34.302	1.52
Decrease rain and increase No (animal and population) and increase irrigation area and construct Dam 2- Dams and Torda Dam	8.750	17.839	8.750	9.089	50.952	2.04

d) Combined effects of changing demand and supply Tandalti downstream User

Table 4.47: Combined effects of changing demand and supply Tandalti downstream User

Impact of combined effect						
Scenarios	Tandalti (dawn stream User)m^3/s					
	Annual Supply	Demand	Used	Deficit	Deficit %	Excess water
Base(2012)	0.420	0.606	0.420	0.186	30.674	1.44
Impact of combined effect of change of(climate, area to irrigate) decrease rain and increase area	0.609	1.084	0.609	0.475	43.803	1.78
Impact of combined effect of change of(climate, population , live stock) decrease rain and increase No	0.731	2.098	0.731	1.367	65.153	2.87
Decrease rain, increase No and construct Dam On Wadi	0.692	1.812	0.692	1.120	61.812	2.62
Decrease rain, increase No and construct Dam 2- Dams and Torda Dam	0.825	1.815	0.825	0.990	54.556	2.20
Decrease rain and increase No (animal and population) and increase irrigation area	0.573	2.098	0.573	1.525	72.685	3.66
Decrease rain and increase No (animal and population) and increase irrigation area and construct Dam On Wadi	0.585	2.098	0.585	1.227	67.719	3.59
Decrease rain and increase No (animal and population) and increase irrigation area and construct Dam 2- Dams and Torda Dam	0.753	2.098	0.753	1.062	58.497	2.78

4.6 Multi-criteria Approach for Evaluation of possible water resources management scenarios

Multi-criteria analysis to evaluate the possible water resources management scenarios is given in table 4.48. The table indicates the ranking order for the likely expected cases with respect to the five evaluation criteria (mainly flow variability and low wet flow in the most important nodes in the system, and flood Plain Inundation , Food production (ton/a) and Food production (GSD/a).

Table (4.48): Multi-criteria analysis for water resources management scenarios

Water Resource Management Scenarios	Raw Score	Rank
Climate Change Wet Rain fall	3.367	1
Base year (2012)	2.779	2
Erection of dam on Wadi(AT Mid of Wadi-After Torda and before Semih)	2.725	3
Irrigation demand increase area (rainfall 2012)	2.306	4
Irrigation demand increase (Rain of 2030)	2.270	5
Two dams up stream and Torda Dam	2.039	6
Impact of change demand (rainfall 012)	1.898	7
Combined increase human population at(2030) and livestock (2030)	1.788	8
Impact of combined effect of change of (climate, area to irrigation) decrease rain and increase area	1.348	9
Decrease rain and increase No and construct Dam	0.791	10
Decrease rain and increase No (animal and population) and increase irrigation area	0.780	11
Climate Change Dry Rain fall	0.300	12

4.7 Water Shortage Challenges

As seen from baseline analysis and scenario analysis a number of challenges to achieving the objectives of integrated water resource utilization are evident and may be referred to as:

4.7.1 Limited Water Resources and Low Storage Capacity

The desirable scenario is to meet the challenge of providing water in an optimal, sustainable and equitable manner to underpin economic development.

The major problem in the Abu Habil catchment is the growing pressure on the limited available water resources in the catchment in combination with the pronounced ephemeral conditions of the rivers. This situation calls for careful water allocation and water demand management. The Abu Habil catchment is to a large extent an unregulated river system, beside some smaller hafirs and the strategic storage in the Turda. This situation calls for coordinated development of water harvesting structures along Abu Habil and its tributaries as well as other water supply infrastructure to key users.

For the Abu Habil Catchment the following key issues are noted:

Main objective for the water sector is to do the following in a balanced manner -:

- Provide water for basic needs
- Secure water for ecosystem services
- Provide water for productive services

In this context, the following key issues are noted in the Abu Habil Catchment:

a. **Water for meeting basic needs**: The coverage rate for water supply and sanitation for urban and rural areas is still far from the national targets. A large portion of the population has little access to secure and safe water sources. In addition, most of the social infrastructure is in poor condition and the service level is at a minimum. The lack of access to water is reflected by the high prevalence of water-borne diseases and general low score on health indicators.

b. **Water for pro-poor rural development**: Another challenge is food security and hence national efforts are put on improving small scale and subsistence farming. The transition from rain fed farming to irrigated agriculture is an important mean to reduce vulnerability and support propos development. Up-scaling of such initiatives are needed in the catchment area. Livestock keeping is another important livelihood activity. Rural development will require an extensive network of hafirs in the Abu Habil area.

c. **Water for economic development -** Securing water for socio-economic development is a main water resources management challenge. Coverage of small to medium sized reservoirs for secured water supply for irrigation for cash crops is not adequate compared to the aspirations of the stakeholders. The Abu Habil river catchment generally has good potential for irrigation/commercial agriculture and agro-forestry. The irrigators do not have the resources to invest in the basic infrastructure that is in the national interest, for water, energy and roads.

Substantial investment funds will be required for the development of water harvesting infrastructure. The lack of access to water is reflected in the low productivity of existing irrigation schemes. Enhanced economic growth in the area will depend on improved regulation of the rivers, through the implementation of a few dams, regulators and other offtak structures. Consideration so suitability of soils, availability of water resource swains the sub-catchment as well as proximity of markets and market access would also be part of the decision on the development of cash crops farming. Irrigation is a major water use component, and the benefits of efficient water consumption are high. The use of water saving irrigation methods (drip and sprinkler) should therefore be investigated, in particular in connection with establishment of cash crop irrigation.

4.8 The Development Scenarios:

4.8.1 Water Balance Results :

The result of the water balance analysis shows that there is a need for a strengthened water supply infrastructure to ensure the supply of water to cover the future water demand in the area. The largest water deficits occur in the lower Abu Habil area, where an increased population and planned irrigation schemes are factors that increases the water stress. The dam development scenario addresses these problems and gives a good water supply to the upper catchment but increases only to some extent the water supply in Lower Abu Habil. To reach a balanced water supply/demand in the whole catchment a reduction of the planned irrigation schemes in the whole area will be needed.

The result from the Water Balance Analysis indicates that there is potential to cover to a large extent the water demands by the year 2030. To this end, the channel network, and above all, the two strategic tributaries of Khor Kajeer and Khor Tagor have been screened for solutions. It is clear that an integrated approach has to be applied in the screening analysis by considering:

- Adequate sites for strategic water storage mainly in Khor Tagor and Khor Kajeer.

- Adequate sites for smaller hafirs throughout the system to provide convenient local water sources close to the communities.

- Adequate conjunctive use between ground water and surface water resources.

- Other main obstacles to find sustainable solutions to satisfy the water demands in the area on a shorter and longer term perspective.

- Social and Environmental conditions and limitations.

4.8.2 Analysis of development scenario to improve water supply

Definition of possible management and development Options: In Abu Habil the major part of the population and irrigation activities are located in shortage areas where the topography is not well suited for larger water storage Utilize dams for annual flow regulation, whereas smaller dams and hafirs could be constructed. In summary, the proposed development options for increasing water supply should contain main components as listed below to achieve a sustainable short and long term solution.

1- **Upstream**: Construction of intermediate and larger three storage facilities (i.e. Khor Kajeer, Khor Tagor and Umm Tagerger Dams) with sufficient storage capacity to overcome ephemeral conditions and create year-round water availability to cover downstream water demands. These reservoirs will deliver water downstream to the Turda, from where lower Abu Habil and hafirs can be supplied. Distribution channels to be built or rehabilitated as required.

Dams Upstream: Construction of intermediate and larger storage facilities with sufficient storage capacity to overcome ephemeral conditions and create year-round water availability to cover downstream water demands. These reservoirs will deliver water downstream to the Turda, from where lower Abu Habil and hafirs can be supplied.

Table 4.49: 3-dams location and capacities

Dams	Location		capacity Mm^3
	Lat	Long	
Dilling Dam	11.983	29.611	10.000
Tagor Dam	11.752	30.722	30.000
Umm Tgarger Dam	12.416	30.394	40.000

2- **Hafirs Downstream:** Construction/rehabilitation of hafirs, with a limited capacity to cover the needs for periods ranging from some days up to maximum a couple of weeks. These smaller dams will not have capacity to even out annual fluctuations in water availability.

The Abu Habil River catchment accounts for a large number of hafirs and minor water storage facilities. It is suggested to assess this type of water storage structures, due to their importance for the local population. These relatively simple structures are very convenient due to their proximity to the users; at the same time their weaknesses are associated with their simplicity: Design and construction is often less than optimal, with insufficient spillways, lack of seepage prevention, malfunctioning outlets etc. This not only makes them unsafe, but also hard to operate as intended. The operation should secure water for domestic use against pollution, which does not always happen. DIU has foreseen a detailed programme on rehabilitation and upgrading of existing hafirs and also the construction of new ones in the area. Figure 4.9 shows a number of hafirs in the area that would be constructed or rehabilitated.

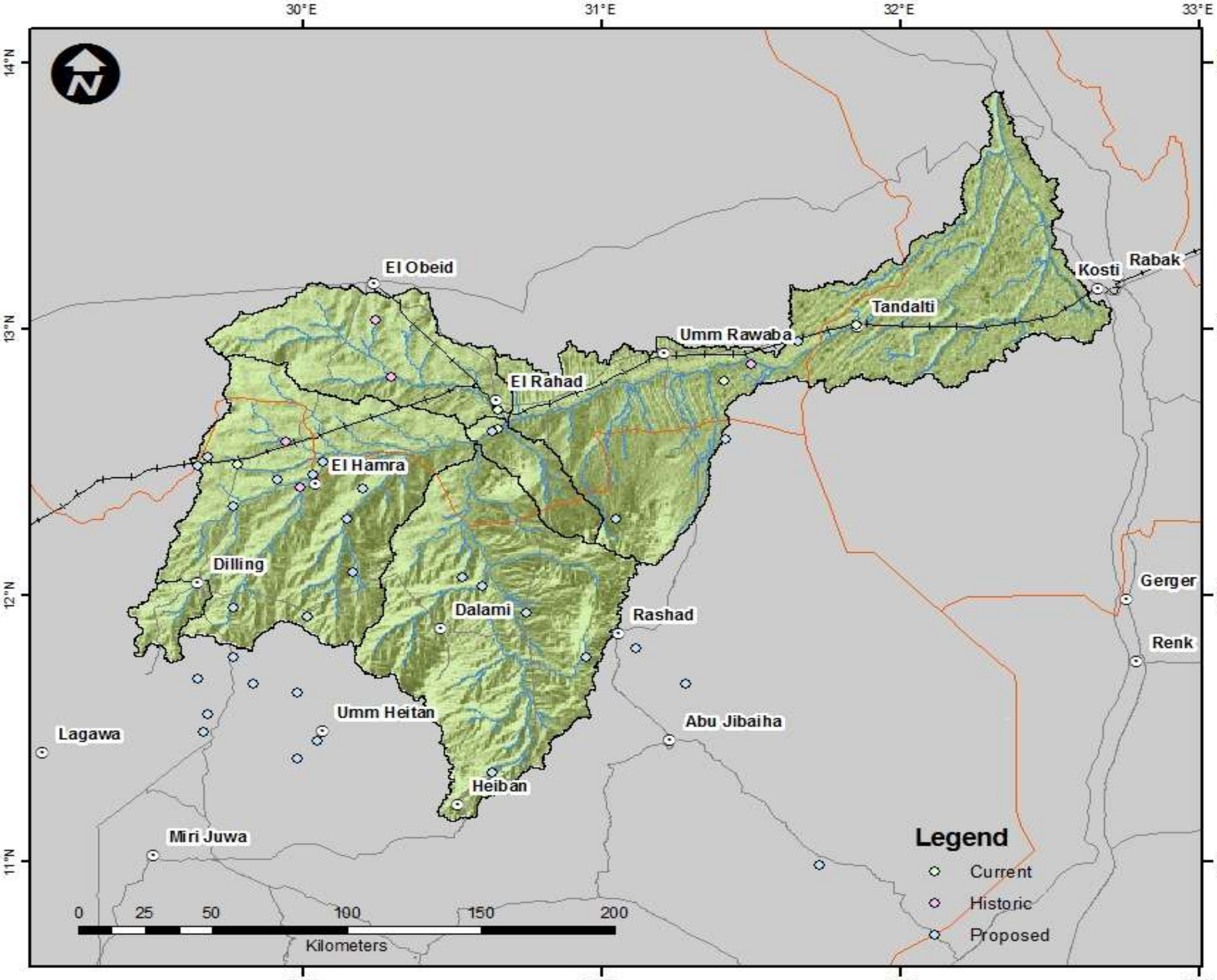


Figure 4.9: Rehabilitation of existing and construction of new hafirs in Abu Habil river catchment.

Table 4.50: Haffirs existing and new location-capacities

Dam	Coordinates	Capacity M m^3
El Rahad Turda	E303917.2; N124142.7	30
Sherkela Turda	E312448.4; N124814.8 25	2
Bangadeed	E301440.1; N130156.5 18	2
Burbur dam	E301754.2; N124909.2 41	12
Sesaban Dam	E295928.2; N122403.5 52	6
Al Dbebat	E294706.8; N122911.5	4
Nabaq Dam	E295643.3; N123423.5	2
Al Gabsha	E313007.0; N125153.2	4
Kamla Dam	E304040.0: N122059.2	3
Zafaia Dam	E305414.3; N124206.5	1
Tendalti		1

Abu Habil accounts for the existing Turda in Er Rahad, connected to the river system through the regulator of Abu Habil. This relatively large storage of water is a strategic and fundamental part of the system that should be optimized as far as possible. It is then possible to utilize Turda water for irrigating the extension areas of El Semeih scheme.

3- Turda Improving Existing hydraulic infrastructure: Review and rehabilitation of existing storage facilities such as the Turda. Some existing structures are for various reasons not utilized to their full potential. Rahad Turda is operated actively as a reservoir by discharging into the river enough water to meet the requirements downstream in Lower Abu Habil.

4- Use of ground water for domestic supply.

This is to include: Dams at Wadi Upstream, Hafirs at Downstream side, Turda Existing hydraulic infrastructure, Conjunctive use of groundwater with surface water for domestic used, and Development of new irrigation Areas

In compiling existing information for the groundwater assessment during the review of resources in chapter 2 it was clearly revealed that the groundwater resources of the catchment are not well documented in terms of availability, occurrence and spatial distribution. Historically, this “hidden” resource has not been given the same attention as surface water despite the fact that groundwater is the dominant source for domestic water supply within the rural communities. The merits of groundwater over surface water can be summarized as follows:

a) Relatively cheap to develop.

b) Resilient to drought through slow decline of water levels due to considerably lower evaporation rates and water volume stored as groundwater is much higher than water stored at surface. Groundwater has thus an increasing importance in adapting to climate change, not only for water supply but also for food security through irrigation of crops. Groundwater is also closely linked to the maintenance of environmental flows.

c) Generally of good quality and without need for treatment.

d) Less susceptible to pollution (however, difficult and expensive to remediate once polluted).

The groundwater assessment undertaken in the review chapter, although rudimentary due to lack of information and data, demonstrated that in terms of volume, groundwater is largely an untapped resource. However, for a major part of the catchment the groundwater exploitation potential is low, which impedes large scale abstraction.

Reliable and efficient groundwater supplies require a deeper understanding of the resource in terms of local availability and occurrence, and most importantly a good management of the groundwater resources. A sound management and a balanced use of the resource will contribute to solve water shortages as well as to meet demand. The most important aspect of groundwater management is monitoring of key parameters (groundwater levels, water quality, pumping rates, etc.). Knowledge of these parameters in space and time is a prerequisite to assess groundwater systems and dynamics, resource assessment, surface-ground water interactions, to enable informed planning decisions.

Development of new and rehabilitation of irrigation Areas For future irrigation demand is presented development scenarios for the potential irrigation schemes and rehabilitation and reconstruction of existing schemes so that the total area is in operation If improved irrigation methods with higher water use efficiency are introduced, the potential irrigation area can be increased considerably.

Erection of three dams, improving Existing hydraulic infrastructure, rehabilitation of Hafirs at Downstream side, use the Turda as storage dam and Use of ground water for domestic supply).

The evaluation procedure of the NB-DSS was used to compare the effects of five options of strategic intervention plans of infra-structures (Construction of Haffirs, Three Dams, Turda Dam) on the basis of well-defined, comprehensive six indicators using multi-criteria approach by expressing the three major principles of Integrated Water Resources Management including: Water availability (Supply), Improvement in Productivity of crops, economic (costs of development), impact and risk on downstream user, and Environmental sustainability The result from the Water Balance Analysis indicates that there is potential to cover to a large extent the water demands by the year 2030 if a set of recommended interventions are applied (Erection of three dams, improving Existing hydraulic infrastructure, rehabilitation of Hafirs at Downstream side, and use the Turda as storage dam).

Multi-criteria module of the NBDSS is employed to evaluate the defined alternatives using Unit Vector normalization method and Ordinal Rankin weighting method. Figure 4.10 depict Indicator Contribution by Scenario and their respective scores.

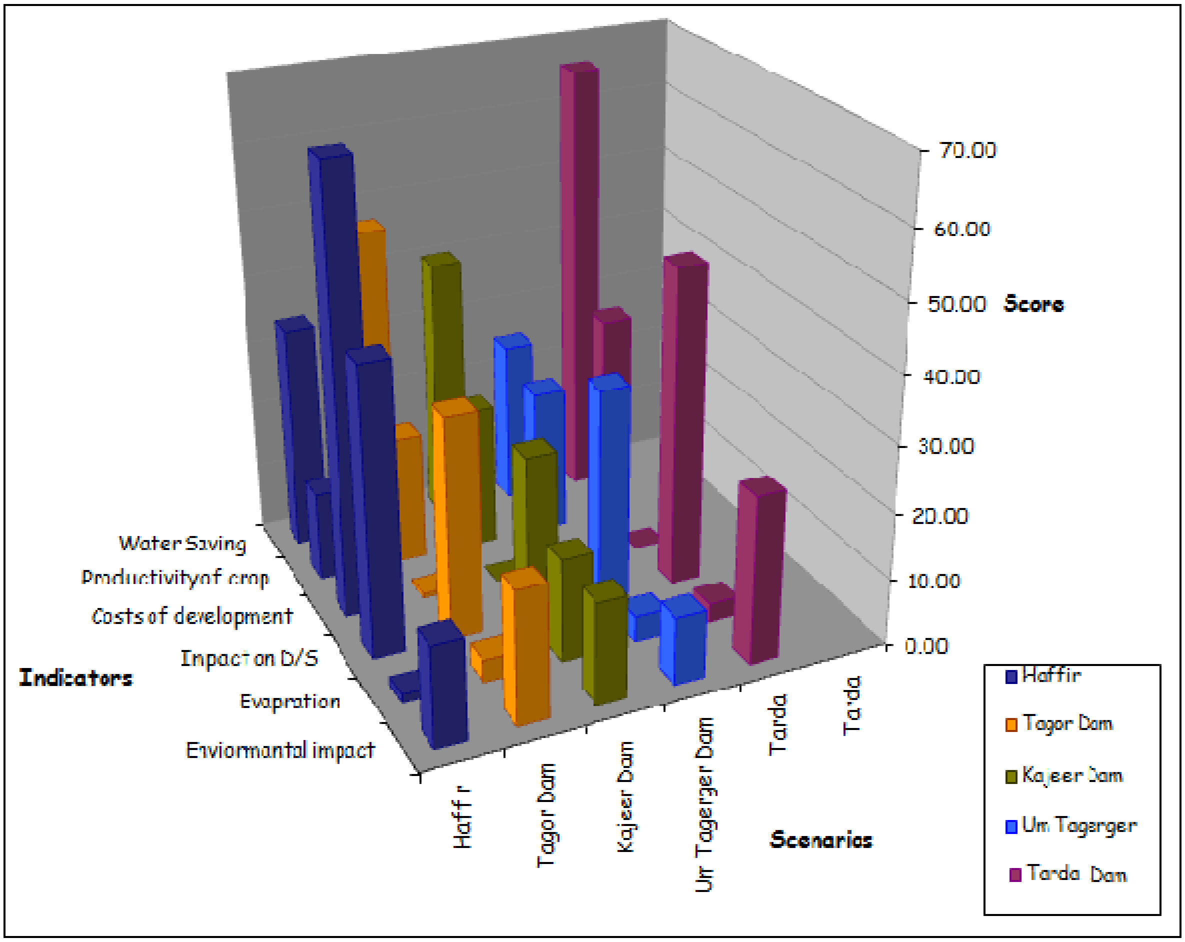


Figure4.10: Indicator Contribution by Alternative intervention Scenario

As shown in table (Table 4.51)the study ranked these alternative options in descending order as: Haffir, Turda, Tagor dam, Kajeer dam and UmTagerger dam. However, a tight control of the growth of the future demands will be needed, although this may be difficult in a rapidly growing developing community.

Table 4.51: Ranking of scenarios according to their achieved scores

	Raw Score	**Rank**
Haffir	174.033	1
Tagor Dam	123.833	3
Kajeer Dam	117.200	4
Um Tagerger Dam	93.333	5
Turda	173.867	2

CHAPTER FIVE
5. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

In this chapter summary, the main conclusions of this study along with the recommendations for future research are presented

5.1 SUMMARY

1- At the end of this chapter the water balances for base year scenario is presented, which is a result of the analysis performed herein. It is noted that Khor Kajeer and Khor Tagor represents 66 % of the water production in the river catchment. The runoff, if efficiently managed, should be enough to cover the water demands that range between 44361.88 Mm^3 in the current scenario and 55036.02 Mm^3 in the year of 2030.

2- A future scenario, “2030 Scenario”, has been set up as predicted scenario to determine the future water demand/deficit situation in the Abu Habil catchment if no change in runoff is taken place up to 2030 (base year runoff is assumed prevailing) which will also enable comparisons with other development scenarios. Water deficit in the present condition (2012) and future scenarios (2030) is given in Table 4.3. The major shortages are registered in Um Tagerger where annual water deficits reach 10.7 Mm^3/year for the present conditions (2012) and increases to 12.9 Mm^3/year in future scenarios (2030). This is followed by Khor Kajeer which is 2.6 Mm^3 and goes up in future to 3.0 Mm^3. The water deficit in the whole basin increases in future from a value of 13.5 Mm^3 to 16.4 Mm^3.However minimum deficient in the present and future cases in Lower Abu Habil.

5.2 CONCLUSIONS

1) The NB-DSS model for the Abu Habil catchment along with the input data used to perform this study have many limitations and a number of assumptions had to be made.

2) The whole Abu Habil catchment was divided into 8 sub-catchments and the hydrologic and water demand data was lumped accordingly. Within a sub-catchment all the individual water demands belonging to the same sector were lumped together, all the water resources generated in the sub-catchment and upstream were available for them and they were given the same water allocation priority.

3) The result from the Water Balance Analysis indicates that there is potential to cover to a large extent the water demands by the year 2030. To this end, the channel network, and above all, the two strategic tributaries of Khor Kajeer and Khor Tagor have been screened for solutions. It is clear that an integrated approach has to be applied in the screening analysis by considering:

- Adequate sites for strategic water storage mainly in Khor Tagor and Khor Kajeer.

- Adequate sites for smaller hafirs throughout the system to provide convenient local water sources close to the communities.

- Adequate conjunctive use between ground water and surface water resources.

- Other main obstacles to find sustainable solutions to satisfy the water demands in the area on a shorter and longer term perspective.

- Social and Environmental conditions and limitations.

4) The expected management Scenario consisting mainly of the impacts of:

- Climate change: increase (wet year) or decrease (dry year) in rain fall
- Erecting new dams
- Changes in water demand
- Decrease in water runoff in Future (Future scenario, “2030 Scenario”, to determine the future water demand/supply situation)
- Combined effects of changing demand and supply:

There increasing demand in Abu Habil watershed due to increase in population and due to climate change. However, the available water storage capacity is limited. This situation calls for careful water allocation and water demand management. The Abu Habil catchment is to a large extent an unregulated river system, beside some smaller hafirs and the strategic storage in the Turda. This situation calls for coordinated development of water harvesting structures along Abu Habil and its tributaries as well as other water supply infrastructure to key users. From the model results and the analysis efficient management of runoff, would be enough to cover the water demands that range between 44361.88 Mm^3 in the current scenario and 55036.02 Mm^3 in the year of 2030

5) Analytical analysis to evaluate the possible water resources management scenarios in reference to the Base year (2012)(including decrees rain and increase Number (animal and population) and increase irrigation Area, decrees rain and increase number and construct Dam ,Climate Change (Wet Rain fall), Climate Change (Dry Rain fall), Irrigation demand increase area (rainfall 2012)resulted in the asset of four conclusions:

i- At Upstream side: Construction of intermediate and larger three storage facilities (i.e. Khor Kajeer, Khor Tagor and Umm Tagerger Dams).

ii- At Downstream side: Construction/rehabilitation of hafirs, with a limited capacity to cover the needs for periods ranging from some days up to maximum a couple of weeks.

iii- Improving Existing hydraulic infrastructure of Turda and use it as reservoir to supplement irrigated agriculture.

iv- Use of ground water for domestic supply.

6) Evaluation of alternative solution interventions (Construction of Haffirs, Three Dams, Turda Dam) using Multi-criteria analysis concluded that implementing of the defined alternatives should be based on their rank and response to the used evaluation indicators of Water availability (Supply), Improvement in Productivity of crops, economic (costs of development), impact and risk on downstream user, and Environmental sustainability and the rank based in the priority order is: Haffir, Turda, Tagor dam, Kajeer dam and UmTagerger dam

5.3 Recommendations

5.3.1 For Policy making

Development Options and Scenario to be implemented for water storage and regulation are:

1. Modernization and heightening of the Turda in Umm Tagerger sub-catchment.
2. Construction of a new dams upstream the city of Dilling.
3. Upgrading of Sesaban dam.
4. Construction of a new dam in the upper part of the Tagor sub-catchment
5. Modernization and rehabilitation of Haffirs
6. Develop proper water governance framework for institutional strengthening and improving water management levels

5.3.2 For Future Studies

It is recommended that other water management challenges not covered in this study due to time and resources constraint that must be addressed are:

- Erosion, sedimentation and water quality problems
- Flood and drought
- Low irrigation efficiency in irrigated schemes

- Study possible water governance framework for institutional strengthening and improving water management levels

▪Increase extension and provide more public awareness

▪Assessment of the impacts of a further development and use of the groundwater resources of the Abu Habil Catchment

▪Assessment of the socioeconomic implications of the different scenarios proposed in this study.

▪For Further refinement of the DSS model it is recommended to add to the model analysis of scenarios the definition of proper strategic option to be applied to the simulated water resource system so as to improve negative situation .The modeling packages presented lack of a framework for defining strategies: they support the visualization of results both in graphical and table format but leave to the technical user or the decision maker the further step of drawing conclusions and imagine suitable strategic measures.

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APPENDICES

APPENDIX 1

Shows the monthly data averaged over thirty years for all 44 Weather Stations.

Weather Station 1

Month	Max. Temp. C°	Min. Temp. C°	RH%	Wind Speed (m/s)	Sun shine (hours
Jan	30.075	14.687	3.882	0.376	22.176
Feb	29.932	15.472	3.745	0.297	22.263
Mar	36.189	19.654	3.954	0.284	26.392
Apr	37.703	21.106	3.382	0.309	25.645
May	38.076	24.289	3.304	0.469	21.817
Jun	34.223	24.03	3.721	0.589	17.831
Jul	30.474	22.679	3.814	0.783	15.693
Aug	29.651	21.789	3.484	0.857	15.707
Sep	31.477	21.41	3.153	0.747	15.504
Oct	33.49	21.842	3.327	0.589	17.531
Nov	29.894	17.607	3.935	0.473	18.959
Dec	30.579	15.317	3.615	0.387	21.142

Weather Station 2

Month	Max. Temp. C°	Min. Temp. C°	RH%	Wind Speed (m/s)	Sun shine (hours
Jan	33.189	14.831	3.114	0.25	24.884
Feb	33.248	15.611	2.94	0.16	25.224
Mar	40.223	20.253	3.104	0.136	29.789
Apr	42.103	22.069	2.563	0.149	29.406
May	43	25.891	2.555	0.306	25.925
Jun	39.268	25.544	2.97	0.42	21.933
Jul	35.64	23.954	2.922	0.617	19.697
Aug	35.336	23.011	2.521	0.676	20.008
Sep	37.752	22.61	2.133	0.549	20.206
Oct	40.278	23.281	2.179	0.37	22.588
Nov	36.237	18.379	2.64	0.233	24.184
Dec	33.381	15.412	2.897	0.274	23.594

Weather Station 3

Month	Max. Temp. C°	Min. Temp. C°	RH%	Wind Speed (m/s)	Sun shine (hours
Jan	33.558	15.165	2.973	0.251	24.859
Feb	33.588	15.879	2.794	0.16	25.185
Mar	40.686	20.506	2.929	0.136	29.874
Apr	42.584	22.407	2.422	0.148	29.496
May	43.454	26.318	2.523	0.303	26.21
Jun	39.561	25.992	3.015	0.412	22.35
Jul	36.21	24.365	2.933	0.603	19.983
Aug	36.01	23.368	2.53	0.659	20.201
Sep	38.504	22.859	2.134	0.539	20.401
Oct	40.978	23.554	2.102	0.369	22.874
Nov	36.674	18.545	2.47	0.234	24.174
Dec	33.748	15.674	2.752	0.275	23.577

Weather Station 4

Month	Max. Temp. C°	Min. Temp. C°	RH%	Wind Speed (m/s)	Sun shine (hours
Jan	33.398	14.99	2.843	0.258	24.86
Feb	33.424	15.667	2.674	0.164	25.121
Mar	40.514	20.247	2.801	0.14	29.78
Apr	42.29	22.2	2.339	0.152	29.212
May	42.968	26.156	2.486	0.311	25.424
Jun	38.979	25.808	3.001	0.422	21.516
Jul	35.657	24.163	2.881	0.616	19.031
Aug	35.439	23.224	2.485	0.672	19.411
Sep	38.091	22.698	2.083	0.551	19.482
Oct	40.595	23.438	2.019	0.38	21.98
Nov	36.404	18.176	2.351	0.24	24.069
Dec	33.561	15.41	2.62	0.284	23.588

Weather Station 5

Month	Max. Temp. C°	Min. Temp. C°	RH%	Wind Speed (m/s)	Sun shine (hours
Jan	32.765	14.085	2.687	0.272	24.843
Feb	32.806	14.818	2.554	0.173	25.047
Mar	39.773	19.336	2.712	0.146	29.583
Apr	41.428	21.565	2.328	0.158	28.753
May	41.957	25.662	2.466	0.327	24.292
Jun	38.027	25.228	2.922	0.442	20.182
Jul	34.511	23.496	2.749	0.652	17.702
Aug	34.068	22.66	2.378	0.712	18.209
Sep	36.802	22.374	2.028	0.581	18.363
Oct	39.339	23.236	1.996	0.402	20.697
Nov	35.571	17.493	2.313	0.251	23.923
Dec	32.905	14.517	2.49	0.298	23.575

Weather Station 6

Month	Max. Temp. C°	Min. Temp. C°	RH%	Wind Speed (m/s)	Sun shine (hours
Jan	32.577	14.111	2.637	0.277	24.813
Feb	32.622	14.747	2.503	0.176	24.999
Mar	39.528	19.262	2.681	0.149	29.474
Apr	41.228	21.767	2.336	0.161	28.535
May	41.793	25.863	2.453	0.334	23.944
Jun	37.874	25.153	2.868	0.45	19.891
Jul	34.172	23.366	2.652	0.665	17.32
Aug	33.654	22.571	2.308	0.724	17.896
Sep	36.365	22.41	2.03	0.587	18.313
Oct	38.976	23.632	2.035	0.408	20.396
Nov	35.31	18.153	2.388	0.25	23.861
Dec	32.732	14.887	2.497	0.301	23.534

Weather Station 7

Month	Max. Temp. C°	Min. Temp. C°	RH%	Wind Speed (m/s)	Sun shine (hours
Jan	33.301	16.123	2.768	0.263	24.749
Feb	33.331	16.521	2.557	0.168	24.991
Mar	40.372	20.996	2.678	0.142	29.5
Apr	42.266	23.329	2.281	0.156	28.7
May	42.921	26.896	2.404	0.326	24.682
Jun	38.618	25.874	2.859	0.439	20.886
Jul	34.479	24.072	2.61	0.645	18.084
Aug	34.459	23.261	2.268	0.698	18.632
Sep	37.194	23.225	2.055	0.557	19.473
Oct	39.868	24.835	2.05	0.392	21.269
Nov	35.856	20.11	2.484	0.239	23.858
Dec	33.454	17.057	2.665	0.285	23.454

Weather Station 8

Month	Max. Temp. C°	Min. Temp. C°	RH%	Wind Speed (m/s)	Sun shine (hours
Jan	34.129	17.904	2.681	0.252	24.484
Feb	34.119	18.235	2.422	0.16	24.837
Mar	41.133	22.815	2.457	0.137	29.43
Apr	42.811	24.862	2.024	0.152	28.847
May	42.879	27.909	2.209	0.323	25.427
Jun	38.473	26.659	2.722	0.434	21.904
Jul	35.03	24.813	2.455	0.632	18.783
Aug	35.114	23.939	2.12	0.683	19.25
Sep	37.968	23.965	1.932	0.539	20.555
Oct	41.07	25.944	1.876	0.379	22.159
Nov	36.94	21.744	2.324	0.228	23.663
Dec	34.289	18.809	2.591	0.272	23.19

Weather Station 9

Month	Max. Temp. C°	Min. Temp. C°	RH%	Wind Speed (m/s)	Sun shine (hours
Jan	34.943	18.749	2.391	0.25	24.39
Feb	34.932	18.985	2.145	0.158	24.804
Mar	42.079	23.581	2.147	0.135	29.371
Apr	43.625	25.264	1.745	0.155	28.784
May	43.09	28.127	2.003	0.332	25.377
Jun	38.341	26.853	2.514	0.443	22.007
Jul	34.901	24.952	2.258	0.646	18.656
Aug	34.958	24.015	1.945	0.701	19.13
Sep	37.934	24.032	1.757	0.552	20.603
Oct	41.611	26.225	1.635	0.387	22.2
Nov	37.823	22.476	2.037	0.225	23.509
Dec	35.099	19.648	2.312	0.268	23.108

Weather Station 10

Month	Max. Temp. C°	Min. Temp. C°	RH%	Wind Speed (m/s)	Sun shine (hours
Jan	35.388	19.175	2.126	0.253	24.311
Feb	35.307	19.332	1.92	0.16	24.747
Mar	42.321	23.905	1.933	0.137	29.254
Apr	43.544	25.252	1.582	0.161	28.589
May	42.604	27.973	1.882	0.348	24.914
Jun	37.782	26.642	2.351	0.462	21.69
Jul	34.313	24.738	2.116	0.669	18.206
Aug	34.313	23.83	1.837	0.728	18.739
Sep	37.405	23.813	1.654	0.578	20.102
Oct	41.347	25.912	1.478	0.409	21.624
Nov	38.155	22.598	1.797	0.229	23.341
Dec	35.548	19.987	2.049	0.271	23.046

Weather Station 12

Month	Max. Temp. C°	Min. Temp. C°	RH%	Wind Speed (m/s)	Sun shine (hours
Jan	33.015	14.732	3.446	0.251	23.148
Feb	33.182	15.695	3.242	0.159	23.8
Mar	40.185	20.375	3.405	0.135	28.547
Apr	42.182	22.092	2.729	0.14	28.502
May	43.019	25.555	2.573	0.287	25.333
Jun	39.338	25.513	3.004	0.404	21.561
Jul	35.703	24.217	3.092	0.598	19.118
Aug	35.722	23.331	2.641	0.657	19.264
Sep	38.463	23.168	2.188	0.52	19.228
Oct	40.653	23.863	2.309	0.336	21.614
Nov	36.066	18.811	2.95	0.231	22.566
Dec	33.164	15.459	3.241	0.275	21.685

Weather Station 13

Month	Max. Temp. C°	Min. Temp. C°	RH%	Wind Speed (m/s)	Sun shine (hours
Jan	33.202	15.047	3.255	0.251	23.098
Feb	33.362	15.912	3.061	0.159	23.78
Mar	40.436	20.601	3.216	0.134	28.563
Apr	42.462	22.499	2.607	0.138	28.543
May	43.364	26.224	2.577	0.281	25.55
Jun	39.742	26.012	3.027	0.395	21.913
Jul	36.293	24.582	3.06	0.585	19.265
Aug	36.508	23.62	2.621	0.642	19.26
Sep	39.236	23.458	2.218	0.508	19.479
Oct	41.29	24.348	2.27	0.332	21.796
Nov	36.39	19.113	2.778	0.229	22.548
Dec	33.363	15.78	3.059	0.275	21.637

Weather Station 14

Month	Max. Temp. C°	Min. Temp. C°	RH%	Wind Speed (m/s)	Sun shine (hours
Jan	33.563	15.475	3.094	0.25	22.974
Feb	33.704	16.25	2.902	0.159	23.635
Mar	40.924	20.931	3.029	0.133	28.462
Apr	42.985	22.893	2.459	0.136	28.459
May	43.822	26.708	2.556	0.278	25.642
Jun	40.116	26.497	3.078	0.388	22.141
Jul	36.787	24.99	3.062	0.574	19.333
Aug	37.052	23.966	2.617	0.628	19.179
Sep	39.862	23.73	2.225	0.5	19.647
Oct	41.992	24.684	2.198	0.331	21.915
Nov	36.862	19.415	2.585	0.229	22.434
Dec	33.729	16.168	2.889	0.275	21.526

Weather Station 15

Month	Max. Temp. C°	Min. Temp. C°	RH%	Wind Speed (m/s)	Sun shine (hours
Jan	33.591	15.262	2.856	0.257	22.918
Feb	33.74	15.992	2.688	0.163	23.544
Mar	41.045	20.648	2.812	0.136	28.383
Apr	43.133	22.658	2.307	0.138	28.389
May	43.89	26.752	2.512	0.281	25.579
Jun	40.093	26.644	3.083	0.389	21.976
Jul	36.763	25.083	3.025	0.575	19.044
Aug	37.049	24.073	2.59	0.628	18.942
Sep	39.974	23.773	2.204	0.503	19.456
Oct	42.123	24.619	2.119	0.338	21.68
Nov	36.889	19.074	2.372	0.234	22.348
Dec	33.746	15.882	2.645	0.282	21.466

Weather Station 16

Month	Max. Temp. C°	Min. Temp. C°	RH%	Wind Speed (m/s)	Sun shine (hours
Jan	33.399	14.465	2.594	0.268	22.872
Feb	33.538	15.218	2.463	0.17	23.476
Mar	40.788	19.861	2.629	0.14	28.278
Apr	42.808	22.195	2.231	0.142	28.256
May	43.643	26.719	2.496	0.286	25.286
Jun	39.909	26.653	3.045	0.394	21.635
Jul	36.546	25.021	2.937	0.582	18.629
Aug	36.845	24.046	2.532	0.636	18.679
Sep	39.797	23.888	2.2	0.507	19.181
Oct	41.824	24.684	2.101	0.345	21.323
Nov	36.586	18.453	2.233	0.241	22.267
Dec	33.54	15.086	2.407	0.294	21.434

Weather Station 17

Month	Max. Temp. C°	Min. Temp. C°	RH%	Wind Speed (m/s)	Sun shine (hours
Jan	33.516	14.564	2.488	0.272	22.816
Feb	33.644	15.217	2.345	0.172	23.419
Mar	40.881	19.846	2.533	0.142	28.204
Apr	42.877	22.493	2.208	0.143	28.171
May	43.717	27.102	2.491	0.288	25.192
Jun	39.986	26.889	3.004	0.394	21.741
Jul	36.584	25.187	2.835	0.584	18.585
Aug	36.861	24.25	2.462	0.635	18.701
Sep	39.861	24.213	2.209	0.502	19.389
Oct	41.912	25.241	2.121	0.345	21.272
Nov	36.654	18.93	2.232	0.24	22.188
Dec	33.66	15.417	2.353	0.297	21.378

Weather Station 18

Month	Max. Temp. C°	Min. Temp. C°	RH%	Wind Speed (m/s)	Sun shine (hours
Jan	34.041	15.89	2.522	0.266	22.776
Feb	34.209	16.337	2.317	0.169	23.406
Mar	41.616	20.921	2.451	0.139	28.168
Apr	43.736	23.484	2.118	0.141	28.153
May	44.361	27.634	2.388	0.288	25.336
Jun	40.238	27.192	2.917	0.394	22.094
Jul	36.699	25.481	2.703	0.584	18.722
Aug	36.318	24.554	2.346	0.636	18.861
Sep	39.063	24.617	2.146	0.498	19.927
Oct	41.631	26.01	2.059	0.343	21.561
Nov	37.262	20.197	2.248	0.234	22.129
Dec	34.206	16.829	2.425	0.289	21.329

Weather Station 19

Month	Max. Temp. C°	Min. Temp. C°	RH%	Wind Speed (m/s)	Sun shine (hours
Jan	34.311	17.1	2.388	0.262	22.731
Feb	34.443	17.495	2.16	0.166	23.404
Mar	41.697	22.094	2.226	0.137	28.149
Apr	43.579	24.351	1.882	0.142	28.095
May	43.731	27.978	2.135	0.297	25.257
Jun	39.425	27.333	2.684	0.404	22.094
Jul	35.942	25.534	2.462	0.599	18.534
Aug	35.943	24.56	2.117	0.652	18.75
Sep	38.864	24.689	1.926	0.505	20.07
Oct	41.921	26.514	1.823	0.346	21.569
Nov	37.395	21.244	2.09	0.231	22.039
Dec	34.454	18.008	2.31	0.283	21.285

Weather Station 20

Month	Max. Temp. C°	Min. Temp. C°	RH%	Wind Speed (m/s)	Sun shine (hours
Jan	34.767	17.741	2.139	0.262	22.662
Feb	34.859	18.076	1.938	0.166	23.385
Mar	42.063	22.644	1.98	0.138	28.073
Apr	43.701	24.47	1.647	0.147	27.894
May	43.498	27.819	1.898	0.311	24.858
Jun	38.955	27.168	2.44	0.42	21.772
Jul	35.367	25.309	2.24	0.625	18.108
Aug	35.319	24.285	1.923	0.683	18.386
Sep	38.405	24.403	1.718	0.528	19.816
Oct	41.888	26.474	1.575	0.36	21.093
Nov	37.815	21.743	1.858	0.23	21.906
Dec	34.907	18.633	2.069	0.282	21.229

Weather Station 21

Month	Max. Temp. C°	Min. Temp. C°	RH%	Wind Speed (m/s)	Sun shine (hours
Jan	35.121	18.346	1.959	0.264	22.591
Feb	35.098	18.624	1.796	0.166	23.354
Mar	42.153	23.173	1.842	0.139	27.968
Apr	43.528	24.607	1.513	0.153	27.71
May	43.051	27.742	1.771	0.327	24.51
Jun	38.422	26.967	2.29	0.439	21.544
Jul	34.782	25.079	2.111	0.648	17.93
Aug	34.661	24.078	1.825	0.709	18.172
Sep	37.866	24.178	1.617	0.553	19.556
Oct	41.554	26.192	1.432	0.381	20.603
Nov	37.99	22.039	1.697	0.232	21.768
Dec	35.274	19.157	1.885	0.283	21.185

Weather Station 23

Month	Max. Temp. C°	Min. Temp. C°	RH%	Wind Speed (m/s)	Sun shine (hours
Jan	32.839	13.969	3.851	0.26	23.067
Feb	33.063	15.051	3.611	0.164	23.767
Mar	40.004	19.82	3.78	0.136	28.605
Apr	42.035	21.864	3.01	0.133	28.631
May	42.939	25.463	2.755	0.267	25.605
Jun	39.533	25.583	3.205	0.384	21.677
Jul	36.027	24.559	3.429	0.575	19.131
Aug	35.884	23.696	2.912	0.634	19.238
Sep	38.504	23.61	2.38	0.492	19.265
Oct	40.46	24.108	2.545	0.312	21.743
Nov	35.912	18.356	3.286	0.236	22.513
Dec	33.002	14.735	3.643	0.286	21.606

Weather Station 24

Month	Max. Temp. C°	Min. Temp. C°	RH%	Wind Speed (m/s)	Sun shine (hours
Jan	33.017	14.384	3.734	0.258	23.029
Feb	33.215	15.379	3.495	0.164	23.743
Mar	40.201	20.163	3.647	0.135	22.559
Apr	42.209	22.306	2.912	0.131	22.57
May	43.109	26.062	2.75	0.264	23.473
Jun	39.7	25.994	3.227	0.38	21.616
Jul	36.25	24.785	3.384	0.571	18.824
Aug	36.235	23.887	2.879	0.627	18.893
Sep	38.857	23.856	2.395	0.487	19.205
Oct	40.878	24.655	2.493	0.309	21.593
Nov	36.191	18.791	3.163	0.234	22.473
Dec	33.185	15.171	3.532	0.284	21.556

Weather Station 25

Month	Max. Temp. C˚	Min. Temp. C˚	RH%	Wind Speed (m/s)	Sun shine (hours
Jan	33.271	14.832	3.618	0.257	22.923
Feb	33.437	15.742	3.381	0.163	23.612
Mar	40.497	20.521	3.516	0.134	28.421
Apr	42.481	22.725	2.822	0.13	28.396
May	43.398	26.535	2.765	0.262	25.383
Jun	39.933	26.413	3.284	0.375	21.658
Jul	36.521	25.081	3.38	0.564	18.683
Aug	36.557	24.155	2.874	0.618	18.634
Sep	39.19	24.147	2.426	0.481	19.281
Oct	41.347	25.116	2.45	0.308	21.509
Nov	36.541	19.218	3.025	0.232	22.374
Dec	33.45	15.631	3.413	0.283	21.465

Weather Station 26

Month	Max. Temp. C˚	Min. Temp. C˚	RH%	Wind Speed (m/s)	Sun shine (hours
Jan	33.481	14.996	3.386	0.26	22.846
Feb	33.637	15.825	3.173	0.165	23.528
Mar	40.786	20.567	3.307	0.135	28.379
Apr	42.813	22.794	2.682	0.131	28.387
May	43.73	26.811	2.75	0.262	25.634
Jun	40.23	26.741	3.309	0.372	21.981
Jul	36.798	25.345	3.351	0.558	18.844
Aug	36.903	24.418	2.859	0.611	18.713
Sep	39.637	24.391	2.449	0.476	19.587
Oct	41.799	25.352	2.4	0.31	21.677
Nov	36.81	19.353	2.821	0.233	22.306
Dec	33.653	15.803	3.183	0.285	21.379

Weather Station 27

Month	Max. Temp. C°	Min. Temp. C°	RH%	Wind Speed (m/s)	Sun shine (hours
Jan	33.739	15.005	3.11	0.265	22.77
Feb	33.89	15.771	2.921	0.168	23.438
Mar	41.13	20.463	3.07	0.136	28.31
Apr	43.206	22.865	2.534	0.131	28.414
May	44.088	27.148	2.717	0.262	25.928
Jun	40.522	27.115	3.292	0.369	22.372
Jul	37.117	25.664	3.276	0.552	19.1
Aug	37.311	24.743	2.816	0.602	19.055
Sep	40.05	24.801	2.465	0.469	19.994
Oct	42.225	25.649	2.354	0.311	21.889
Nov	37.08	19.361	2.617	0.235	22.223
Dec	33.902	15.807	2.922	0.29	21.302

Weather Station 28

Month	Max. Temp. C°	Min. Temp. C°	RH%	Wind Speed (m/s)	Sun shine (hours
Jan	34.126	15.23	2.916	0.267	22.712
Feb	34.288	15.911	2.722	0.169	23.377
Mar	41.609	20.576	2.875	0.137	28.255
Apr	43.692	23.13	2.413	0.131	28.416
May	44.451	27.517	2.658	0.262	25.991
Jun	40.705	27.46	3.231	0.367	22.694
Jul	37.342	25.98	3.144	0.549	19.266
Aug	37.532	25.09	2.719	0.596	19.272
Sep	40.352	25.207	2.431	0.462	20.309
Oct	42.718	26.101	2.293	0.31	22.014
Nov	37.494	19.607	2.485	0.235	22.147
Dec	34.288	16.049	2.757	0.292	21.25

Weather Station 29

Month	Max. Temp. C°	Min. Temp. C°	RH%	Wind Speed (m/s)	Sun shine (hours
Jan	34.556	15.657	2.728	0.268	22.678
Feb	34.747	16.252	2.519	0.17	23.368
Mar	42.221	20.903	2.648	0.138	28.198
Apr	44.362	23.397	2.24	0.132	28.327
May	44.842	27.643	2.477	0.267	25.732
Jun	40.717	27.518	3.038	0.372	22.561
Jul	37.24	26.014	2.903	0.558	19.035
Aug	37.386	25.122	2.505	0.606	19.087
Sep	40.485	25.267	2.256	0.466	20.349
Oct	43.259	26.405	2.124	0.313	21.88
Nov	38.012	20.019	2.348	0.234	22.078
Dec	34.712	16.49	2.603	0.293	21.212

Weather Station 30

Month	Max. Temp. C°	Min. Temp. C°	RH%	Wind Speed (m/s)	Sun shine (hours
Jan	34.499	16.267	2.394	0.27	22.64
Feb	34.652	16.828	2.201	0.171	23.35
Mar	41.929	21.481	2.297	0.139	28.117
Apr	43.869	23.722	1.935	0.136	28.15
May	44.122	27.609	2.126	0.28	25.286
Jun	39.906	27.367	2.657	0.387	22.194
Jul	36.331	25.756	2.523	0.582	18.554
Aug	36.252	24.808	2.171	0.635	18.728
Sep	39.295	24.977	1.936	0.485	20.16
Oct	42.294	26.476	1.813	0.326	21.446
Nov	37.721	20.533	2.084	0.235	21.976
Dec	34.657	17.098	2.3	0.294	21.18

Weather Station 31

Month	Max. Temp. C°	Min. Temp. C°	RH%	Wind Speed (m/s)	Sun shine (hours
Jan	34.809	16.821	2.073	0.272	22.582
Feb	34.865	17.305	1.917	0.172	23.325
Mar	42.064	21.914	1.998	0.141	28.027
Apr	43.787	23.808	1.66	0.142	27.97
May	43.879	27.408	1.831	0.294	24.962
Jun	39.538	27.172	2.35	0.403	22.102
Jul	35.784	25.494	2.236	0.607	18.359
Aug	35.613	24.497	1.931	0.665	18.621
Sep	38.878	24.628	1.689	0.509	20.103
Oct	42.101	26.317	1.55	0.342	21.042
Nov	37.904	20.954	1.826	0.237	21.873
Dec	34.969	17.66	1.996	0.295	21.129

Weather Station 32

Month	Max. Temp. C°	Min. Temp. C°	RH%	Wind Speed (m/s)	Sun shine (hours
Jan	35.237	17.638	1.888	0.271	22.505
Feb	35.135	18.009	1.768	0.171	23.314
Mar	42.22	22.582	1.848	0.14	28
Apr	43.694	24.177	1.528	0.144	27.886
May	43.662	27.503	1.709	0.307	24.944
Jun	39.208	27.127	2.23	0.42	22.452
Jul	35.507	25.422	2.132	0.622	18.794
Aug	35.062	24.363	1.836	0.691	18.769
Sep	38.514	24.462	1.594	0.532	20.325
Oct	41.902	26.145	1.429	0.361	21.021
Nov	38.092	21.434	1.668	0.237	21.762
Dec	34.377	17.874	1.761	0.283	20.462

Weather Station 34

Month	Max. Temp. C°	Min. Temp. C°	RH%	Wind Speed (m/s)	Sun shine (hours
Jan	33.166	12.496	4.042	0.281	22.906
Feb	33.35	13.624	3.792	0.181	23.689
Mar	40.289	17.94	3.974	0.151	28.585
Apr	42.35	19.617	3.202	0.151	28.662
May	43.375	23.791	2.96	0.272	25.561
Jun	40.04	25.188	3.495	0.37	21.69
Jul	36.551	24.955	3.884	0.55	18.972
Aug	36.066	24.241	3.281	0.61	18.957
Sep	38.486	24.111	2.666	0.464	19.31
Oct	40.54	23.766	2.742	0.297	21.592
Nov	36.107	17.037	3.434	0.253	22.387
Dec	33.163	13.112	3.837	0.312	21.472

Weather Station 36

Month	Max. Temp. C°	Min. Temp. C°	RH%	Wind Speed (m/s)	Sun shine (hours
Jan	32.744	12.547	3.89	0.309	21.988
Feb	31.765	12.464	3.698	0.212	22.445
Mar	39.133	17.064	3.964	0.17	27.508
Apr	41.084	18.779	3.456	0.143	28.367
May	44.137	22.577	2.915	0.22	27.27
Jun	41.069	25.086	3.167	0.328	22.536
Jul	38.225	25.718	3.883	0.485	19.414
Aug	35.742	24.459	3.507	0.604	18.243
Sep	37.04	23.88	2.837	0.532	18.722
Oct	41.034	25.16	2.632	0.361	20.317
Nov	37.789	19.977	3.116	0.243	22.246
Dec	34.602	14.825	3.664	0.296	21.789

Weather Station 41

Month	Max. Temp. C°	Min. Temp. C°	RH%	Wind Speed (m/s)	Sun shine (hours
Jan	34.871	14.518	2.544	0.291	22.534
Feb	34.915	15.174	2.387	0.187	23.276
Mar	42.265	19.272	2.515	0.16	28.063
Apr	44.511	20.777	2.069	0.163	28.14
May	44.88	25.067	2.122	0.287	25.268
Jun	40.683	26.36	2.622	0.38	22.345
Jul	36.785	25.78	2.646	0.566	18.849
Aug	36.538	25.094	2.315	0.615	19.053
Sep	39.702	25.017	1.993	0.468	20.304
Oct	42.674	25.35	1.872	0.32	21.229
Nov	38.103	18.846	2.233	0.255	21.915
Dec	35.052	15.328	2.431	0.318	21.08

Weather Station 42

Month	Max. Temp. C°	Min. Temp. C°	RH%	Wind Speed (m/s)	Sun shine (hours
Jan	35.126	14.904	2.096	0.295	22.488
Feb	35.074	15.416	1.981	0.189	23.252
Mar	42.363	19.377	2.101	0.162	27.998
Apr	44.462	20.384	1.733	0.17	28.078
May	44.817	24.525	1.795	0.3	25.206
Jun	40.542	26.219	2.267	0.393	22.648
Jul	36.471	25.621	2.281	0.585	19.149
Aug	36.108	24.895	2.013	0.637	19.375
Sep	39.421	24.713	1.718	0.487	20.662
Oct	42.554	24.917	1.585	0.337	21.21
Nov	38.213	19.085	1.888	0.258	21.837
Dec	35.316	15.748	2.013	0.32	21.029

Weather Station 43

Month	Max. Temp. C°	Min. Temp. C°	RH%	Wind Speed (m/s)	Sun shine (hours
Jan	35.391	15.605	1.872	0.295	22.448
Feb	35.254	16.09	1.783	0.188	23.25
Mar	42.438	20.057	1.901	0.159	27.982
Apr	44.364	20.557	1.563	0.173	28.039
May	44.654	24.431	1.649	0.31	25.352
Jun	40.265	26.372	2.136	0.403	23.163
Jul	36.215	25.569	2.122	0.598	19.697
Aug	35.805	24.797	1.881	0.653	19.872
Sep	39.212	24.543	1.601	0.504	21.075
Oct	42.435	24.293	1.43	0.358	21.407
Nov	38.316	19.418	1.7	0.258	21.767
Dec	35.583	16.411	1.798	0.318	20.981

APPENDIX 2

Nile Basin Decision Support System (NB-DSS), Modeling Tools and Procedure

1- Using the Database manager utility to login and use the DSS includes creating, backing up, dropping, restoring and updating databases, users must have a username, a password and an access level

2- Create a connection database within the DSS and activate the 'System' manager

3- Chooses the simulation options in main window of MIKE ZERO interface by a dialog box.

4- Drew in basin schematization as a network of nodes and branches. As in large river basins the description of numerous individual demands and features takes a lot of time and efforts, some networks can be simplified according to objectives of the modeling and availability of data.

5- The Schematic network can be drawn on a geographic map showing the hydrograph of the area on a geographic map of interest. At first the user digitizes manually the main river and his tributaries in terms of a poly line following the trace on the map. Then he places the nodes in the following order: River Nodes, Reservoirs, and Water demand nodes.

River nodes are placed on the river poly line and are Simple or Catchment type. The former define confluences, diversions, upstream end of tributaries and the outlet of the river system whilst the latter is the outlet of an upstream catchment area. These areas are depicted hatched in green colour in the specific Runoff layer. A Simple or Catchment node can assume the further feature of Offtake Node when it is connected to demand nodes. Reservoir nodes are placed on top of river nodes. Water demand nodes are placed at last and represent irrigation sites and water supply systems conveying water to cities or industries. NB-DSS has an Access database but data for each network element is easily edited or viewed from the Network View. NB-DSS is set to Attribute Mode and pop-up menus specific to each kind of node open at the right-click on the node itself. Through these menus the user is provided with proper dialog boxes where he can specify properties and time-series. For instance, the catchment area’s box concerns the area in square kilometers and the definition of the runoff time series

6- Editing launching the Time Series Edit tool (TSedit). This tool’s interface has two different panels. The table can also be created in Excel and then imported with a copy and paste operation.

7- Select in simulation window when start and end dates of the simulation period and to choose between a monthly or daily time steps.

8- Select Rainfall-Runoff Modeling dialog box that is accessed from the generic catchment node box. In the same box he can choose among three different rainfall-runoff models that are part of another DHI software package named Mike 11. The models are NAM, SMAP and UHM.

The NAM is a conceptual model originally developed by the Department of Hydrodynamics and Water Resources at the Technical University of Denmark. It simulates the rainfall-runoff processes occurring at the catchment scale and calculates in particular surface-overland flows, interflows and base flows as a function of the soil moisture content, surface storage and accumulation and melting of snow. It is lumped type, so it treats each catchment as a single unit whose variables assume average weighted values for the entire area. The NAM parameters are estimated through proper calibrations against time series of physical data observations. The input requirements of NAM are moderate and consist of 1) basic meteorological data, such as rainfall and evapotranspiration 2) some additional data of temperature and radiation used by the snow modeling 3) observed discharge data at the catchment outlet, to be compared with the model output for validation and calibration purposes 4) water used for irrigation and 5) pumping rates from aquifers. The time scale of meteorological data is different for each kind of time series: for rainfall it depends on the time scale of the catchment response but usually daily values are sufficient, potential evapotranspiration can be provided as monthly values while temperature as daily mean values.

NAM comprises Basic modeling module, Extended Groundwater module, Snow module, and Irrigation module.

The basic module of NAM simulates the overland flows, infiltration and aquifer recharge, interflows in the root zone and the base flow in aquifers. Moisture intercepted by vegetation and cropped areas as well as accumulated in depressions is conceived as a surface storage whose outflows are due to evapotranspiration and infiltration. The water amount exceeding the surface storage capacity generates the surface land flows feeding streams. The soil layer below the surface is schematized as the root zone storage receiving water for infiltration and losing water for roots transpiration, interflows and deeper infiltration recharging the aquifers.

The Extended Groundwater module of NAM describes the water balance of the Groundwater Storage by considering recharge, capillary flux, net groundwater abstractions and base flow. Groundwater storage is described as a lower storage with usually has a slow responding component of the base flow and an upper storage providing a faster response. They are studied both as linear reservoir. The capillary flux of water from the groundwater to the root zone is a function of the depth of the water table below the ground surface and the moisture content of the root zone. This module of NAM also considers the possible drainage of water to or from neighboring catchments due to local geology and geomorphology. The amount of recharging water feeding near catchments or coming from them is calculated as a proportion of the total recharge multiplied by the ratio of groundwater catchment area over topographical catchment area.

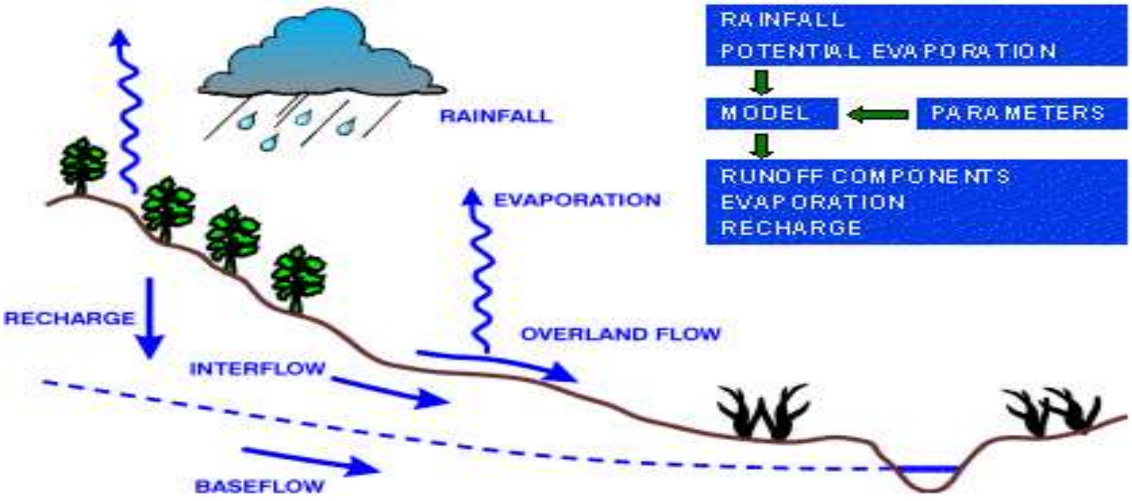

Fig.3.4: The schematic of natural phenomenon for the NAM model (from Elshamy 2012)

The irrigation module of NAM takes into account the weight of large agricultural areas in the global water balance of the catchment. They affect the runoff distribution in terms of local water abstractions, from aquifers and rivers, and of increased local infiltration and groundwater recharge on the other side. Increased evapotranspiration and possible external water transfers for irrigation too have not negligible influence on catchment hydrology. The conceptual approach is to define each large irrigation site as a sub-catchment described by its own individual parameters such as irrigation losses to evaporation, seepage and overland flows. Monthly Crop coefficients to consider the proper evapotranspiration and stage of growth are used as well.

9- View simulation results consist of performance of reservoirs and hydropower units, water balance and water quality status at the user nodes and river flows at each river node. Information is displayed in three different formats:

· As time series and related graphs

· Summary HTML tables

· On the geographic layer

10- Open BN-DSS and import models from a number of modeling packages

11- Creating and running Scenario and viewing the results, the simulation results can be accessed directly from the scenario manager or from the time series manager. Each scenario run is called a 'Simulation

12- Indicator (in the DSS): A model indicator is an entity that links one or more model output variables to a script that accepts a corresponding set of input parameters. The script will process the model output in a user defined way, and return the so-called indicator value (a scalar value).Each scenario run is called a 'Simulation.

13- Registering models and managing scenario in the DSS ,users need to be aware that in order to register a model to the DSS the following is required:

- The model has to be fully developed in a modeling package (including any necessary calibration)
- The model has to successfully run within the modeling package, and its results are thoroughly checked and proved to be reasonable

14- can be compare scenario results within the ‘Scenario’ manger Three methods exist to do this task in the DSS, namely:

- Direct comparison where data is plotted or tabulated against each other. This methods allows direct visual comparison is needed and it can be used when two or three scenario need to be compared. If more scenarios need to be compared, it is advisable to used one the below methods.
- Using the comparison configuration where a configuration is defined with those scenario elements that need to be compared. This method is useful when more than the direct comparison

is needed such as comparing duration curves of an output time series from two simulations or more.

- Using indicators where indicators are defined at the model setup level and they are calculated each time a scenario is run. This method is useful when quantitative comparison is needed between scenarios. These indicators can be used in results comparison and/or in advanced analysis such as the Multi Criteria Analysis (MCA).

15- Optimization is an important tool in making decisions and in analyzing physical systems. optimization includes finding ‘best available’ values of some objective function given a defined domain

16- To Create a MCA Setup chooses weights are made and the magnitude of the objective functions relative to each other does not affect the final set of optimal solutions. This gives us the possibility of choosing the weights after the execution of the optimization, and then selecting a point that has the lowest values of the aggregated objective function. This way the effect of choosing different weights can also be investigated. The downside of the multi-objective methods is that the search for the entire Pareto front is computationally more expensive than the “specialized” search carried out by the single-objective algorithms.

17- Used to Normalization method at all criteria values to dimensionless values between 0 and 1

18- Create a table of all indicator values for a model ,All model scenarios are included

19- Indicator values are taken from the latest simulation

20- User can add additional and Remove scenarios from other model setups

21- User can create a comparison and run the comparison tool to see compare results and select acceptable scenario or solution.