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Hydrological Study Analysis and Groundwater Assessment of Hadramawt Aquifers, May 2022

by Dr. Abdulwahed Ali Iskander

Abstract:

Hydrological study in Hadramawt is composed of several sections. The first section introduces the hydrological aspects to be covered and analyzed which includes parameter of surface water as rainfall, runoff scale in relation to geology composition and soil moisture and characteristic. Background of the study area in terms of location, topography and classification of Hadramawt aquifers are disused in this study. Research objectives pertinent to groundwater resource assessment in Hdramawt are successfully achieved through examination of enormous data variables of rainfall and surface runoff data that was collected covering longtime period over 40 years. Time series of rainfall are used to reveal rainfall pattern in the concerned area and examine its temporal and spatial distribution at annual, seasonal and monthly averages Rainfall distribution and other climatic opponents are discussed in relation to other meteorological data. Several formula and models appropriate to water assessment are applied and mentioned under methodology section and further explored in the hydrologic analysis section.

The researcher undertakes thoroughly the hydrological analyses, which combine various components of water resources variables in order to make reliable assessment, the type and amount, of water resources at the surface and underground level within regional and local aquifers. Catchment areas in relation to rainfall and runoff parameters are used to estimate groundwater recharge rates. Comparative analysis is performed to contrast water abstraction with recharge rate in order to establish a baseline defining critical basins within concerned study areas in Hadramawt governorate and main basins of targeted project areas. Components of groundwater system and water saving as a consequence of the implementation of the proposed project are consequently discussed in the analytical section. Monitoring and evolutional aspects of the project explore the current situation of water balance by defining the extent of groundwater availability and depletion at a district level. The magnitude of water balance is pictured and charted in a detailed map for the Hadramawt project, so as to better control and monitor

groundwater use based on location and using sustainable management methods to reserve water resources within the context of tasks achievements and practicing water saving activities under the suggested programs for Hadramawt Modern Irrigation Projects (MIP) to be implemented in the concerned area. A list of hydro and meteorological devices and equipment needs are developed to support monitoring and evolution processes of the project. Finally, concluding marks and research recommendations are abstracted at the end of this study.

Hydrological analysis assessment revealed that the total annual groundwater recharge into the aquifers of Hadramawt governorate basins is at 151 MCM / in 2008 as the recharge aggregated for the 11 sub-basins in the governorate. The total Irrigated Area from groundwater in Hadramawt Governorate was 13,551 hectare in the same year, consumed (MCM169) million cubic meters, an amount accounted for irrigation from groundwater, which exceeds the amount of annual water recharge. This situation of groundwater system would leads to acute shortage in water supply over years to come, however, applying modern technology in irrigation would save 67.7 MCM/year of groundwater, assuming that all irrigated land be covered with modern irrigation techniques in Hadramawt Governorate.

ملخص: الدراسة الهيدرولوجية لتقدير المياه الجوفية في محافظة حضرموت:

شملت الدراسة الهيدرولوجية لحضرموت العديد من المتغيرات القياسية للمياه الجوفية المتوفرة في الأحواض المائية المغذية للمياه الجوفية في محافظة حضرموت بغرض تحديد كمية المياه الجوفية المستخدمة سنوياً في الري الزراعي. من خلال دراسة العلاقة بين متغيرات كمية المياه السطحية والجريان في أودية حضرموت ومتغيرات المياه الجوفية والمخزون المائي في أحواض حضرموت وقام الباحث بفحص هذه العلاقة مستخدماً نماذج القياس الهيدرولوجي المعتمدة وتطبيق التحليلات الإحصائية المناسبة في حساب كمية المياه المتجددة بالاعتماد على سجلات المناخ والأرصاد الميترولوجية المتوفرة لفترة تقارب 40 عاماً من الأرصاد الجوية المتعلقة بكمية الأمطار الساقطة، متوسطات الحرارة، البخر والنحت إضافة إلى حساب كمية الجريان السطحي ومعدل الامتصاص بحسب التركيب الجيولوجي وخواص التربة في الأحواض المائية المتوافقة مع التقسيمات الإدارية للمحافظة.

أن الهدف الرئيس لهذه الدراسة هو توفير البيانات المائية اللازمة وإجراء القياسات المطلوبة لتقدير كمية موارد المياه الجوفية والمتجددة ومقارنتها بالمياه الجوفية المستهلكة للري الزراعي بغرض الحفاظ على المياه الجوفية وترشيد استخدامها وذلك للتقليل من معدل استنزافها عن طريق تطبيق واستخدام الأدوات والوسائل التكنولوجية الحديثة في عملية الري الزراعي كون هذا القطاع

يستهلك/ يستخدم ما نسبته 90% من إجمالي المياه المسحوبة من مخزون المياه الجوفية عن طريق الآبار الإرتوازية. لقد تم تصميم برنامج مشروع الري الحديث في اليمن لمواجهة مشكلة استنزافا المياه الجوفية من خلال استخدام التكنولوجيا الحديثة في الري التي أوصى بها خبراء الزراعة والري بإشراف وزارة الزراعة والري وبالتعاون مع وزارة التخطيط وبدعم من خبراء البنك الدولي. ولتنفيذ هذا المشروع تم البدء بإجراء دراسات شاملة مكونة من خمسة حقول وهي: الدراسة الهيدرولوجية، والدراسة الهندسية لمكونات الري الحديث، والدراسة الاجتماعية والاقتصادية والبيئية وقد غطت الدراسة 20 موقعا شملت معظم محافظات الجمهورية اليمنية. شكلت هذه الدراسة الهيدرولوجية أحد مكونات مشروع الري الحديث والتي قام بتنفيذها الباحث بالإضافة إلى قيامه بالإشراف والتنسيق بين أعضاء ورؤساء الفريق الاستشاري لتنفيذ مهام العمل في فروع الدراسات الأخرى المكونة لمشروع الري الحديث، فضلاً عن قيام الباحث بإعداد التقارير النهائية لهذا المشروع.

ولأن الهدف الأساسي للدراسة الهيدرولوجية/ المائية هو تقدير المياه المسحوبة سنوياً من المخزون المائي لأحواض حضرموت ومقارنتها بمعدل التغذية السنوية للأحواض المائية من خلال المياه المتجددة، فقد قام الباحث بتحليلات هيدرولوجية شاملة تطلبت جمعاً ضخماً للبيانات والسجلات المناخية ذات العلاقة والتي شملت بيانات عن كمية الأمطار والحرارة والتبخر والنتح والاستفادة من دراسة ومراجعة كل التقارير والسجلات المتوفرة المتعلقة بالجريان السطحي ودراسة الخصائص الجيولوجية وطبيعة التربة وقابليتها للامتصاص والاحتفاظ بالرطوبة والقيام بفحص العلاقة بين متغيرات الموارد المائية من خلال تطبيق واستخدم عدد من الموديلات والمعادلات المعتمدة في قياس المياه واستخدام الحسابات المعيارية الخاصة المستخدمة في إجراءات قياس المياه وتطبيق الأساليب الإحصائية المناسبة والشاملة لحساب المعدلات والمتوسطات وإجراء تحليلات التباين واستخدام مؤشرات الانحراف عن المتوسط والمؤشرات الدالة لمدى علاقة الارتباط والصدق والثبات بين المتغيرات والعوامل وغيرها من الحزم الإحصائية المطبقة على البيانات المجموعة من خلال المسح الميداني لعينات الدراسة الممثلة بالإضافة إلى استخدام البيانات المنشورة وغير المنشورة من مصادر ثانوية متنوعة.

وأظهرت نتائج الدراسة الهيدرولوجية لتحليل الوضع المائي في محافظة حضرموت أن عدد الآبار الإرتوازية في تزايد مستمر وقد وصل عددها إلى ما يقارب من 8000 بئر عام 2008م ويصل متوسط عمق الواحد منها بين 100 إلى 150 متر وأظهرت نتائج القياسات بأن مستوى المياه الجوفية يهبط بمعدل يتراوح بين 2-7 متر في السنة، في حين أن معدل التغذية السنوية للمياه الجوفية يبلغ نحو 151 مليون متر مكعب بينما تصل كمية الجريان السنوي للمياه السطحية في أودية حضرموت إلى حوالي 186 مليون متر مكعب وكشفت نتائج الدراسة الهيدرولوجية بأن كمية الأمطار الساقطة على أودية حضرموت لا يتعدى 3130 مليون متر مكعب وأن جزءاً كبيراً منها يفقد بعملية التبخر والنتح وجزء يجري بعيداً عن الأحواض وجزء بسيط من هذه الكمية هو فعلاً ما يمد أحواض المياه بالتغذية المائية في عملية التجدد وهذا يعني أن هناك فارق سلبي في ميزانية نظام المياه الجوفية يبلغ حوالي 35 مليون متر مكعب من المياه والتي يتم استنزافها عن طريق الضخ من الآبار وهذه الكمية لا يمكن تعويضها إلا جزئياً وفقاً للحسابات الهيدرولوجية والظروف المائية السائدة في المحافظة. ولذلك يرى خبراء الري الزراعي أنه بالإمكان التعويض الجزئي عن طريق استخدام

وسائل الري الحديث في الرش والتنقيط وفي نقل المياه وتقليل الفقد إلى حده الأدنى. وفي هذا السياق يوصي الباحث المختصين باستخدام وسائل إضافية مثل تشييد السدود التي تقوم بوظيفتين بنفس الوقت فهي من جهة تعمل على زيادة معدل تغذية المياه الجوفية وتتيح فرصاً أفضل وبتكلفة أقل في الري الزراعي من جهة أخرى.

INTRODUCTION:

Water harvesting in Hadramawt has played and will continue to play an important role in soil conservation and leaching salty soil by surface spate water coming from the mountain slopes in the uplands. However, agricultural land under water harvesting was subjected to serious soil erosion and soil degradation.

Hadramawt governorate has diverse agro-ecological zones. The major zones are Hadramawt Basin areas and Valleys such as Wadi Hadramawt, W.Amad, W. Dawa'n, and Almukalla Basin. Because of this diversity there are distinct agricultural activities of summer and winter crops namely, tropical and subtropical fruits, vegetable crops, feeder natural agricultural crop and medical herbs, which depend mainly on groundwater irrigation.

Hadramawt governorate is situated in one of the poorest country region regarding water resources as the average per capita was hardly over 150 m3/person/years a decade ago but now is not exceeding 114 m3. Rainfall of the catchment areas of the western highland and groundwater are the only sources of water and because the governorate is mostly predominated by arid climate, the rainfall is highly irregular and variable where standard deviations of the annual rainfall are within the ranges of 29-38% of the means in the semi-arid Hadramawt zones. This is coupled with high evapotranspiration potential rates and available surface water can hardly support rain-fed and spate irrigated agriculture.

Hence the focus has been given to assessment of ground water sources and its use for both agricultural and domestic utilization to the extent of over exploiting it. This fact is expressed by the pertinent literature, which exhibits a rapid growth rate in population and in expansion of irrigated agriculture from several hundred hectares in the seventies to 21,874 ha represented 31% as in year 2008 and further expanded in year 2020. Irrigated agriculture is the dominant water consuming sector. It consumes over 90% of water use in the governorate. A rapid dropdown in ground water levels has been monitored and reported in many Hadramawt Valleys and Basins due to the fact that over abstraction and consistent depletion with more new dug wells have become the rule rather than the exception. As for example in Wadi Amd/Doan, Wadi Al Ayn, Wadi Sarr, Wadi Bin Ali a drop down rate of ground water levels in the range of 20-50 m. has been recorded during the last 40 years. These ground water levels were said to be more sustainable in the past and this is attributed mainly to the fact that irrigated agriculture practiced was largely based on spate, floods and shallow manually dug wells.

I. Statement of the Research Problem:

Groundwater is a valuable resource both in Hadramawt and throughout the country of Yemen. Groundwater assessment, a term often defined as a long-term water level measurement involving enormous variable of hydrological data analysis, composing of surface rainfall, runoff water and aquifers characteristic such as geographic, topographic geology natural soil in relation to recharge and discharge. This research study focus on hydrological aspects of Hadramawt aquafers in order to provide reliable measurement tools of water level depletion in concerned areas such as basins, valleys/wadis of Hadramawt where water level declines caused by sustained groundwater pumping is the main issue associated with groundwater use for irrigation that this research aims to tackle.

Since the cultivated area based underground irrigation in Hadramawt represents around 49% of total irrigated land and 30.5% of the total cropped area, yet it produces 75% of the total crops production, and contribute 85% of the value of production, hence as a result the demand for irrigation water has rapidly increased over decades and in many areas exceeded available water resources as the water shortages in these areas is supplemented by over abstraction of the groundwater, which resulted in considerable drop in the groundwater table levels including the reach aquifers of Hadramawt Governorate. Water harvesting and terraces agriculture is continuously subjected to soil erosion and degradation in the uplands and along valleys banks. The spate agriculture is subjected to valleys' bank erosion and the groundwater agriculture is more affected by the over abstraction of groundwater, which led to aquifer depletion in many areas of the governorate under study. This has ultimately led to the fact that groundwater irrigation water becomes the most costly input item. Therefore an extensive data collection on groundwater and long run measurement in terms of hydrological aspect related to surface rainfall, runoff and recharge variables, which of prime importance to groundwater measurement in order to improve irrigation methods and to sustain groundwater through effective mechanism of irrigation use of groundwater. The contribution of this research study could induce economic progress and a sustainable use of groundwater for agriculture irrigation.

II. Research Objectives:

This study objectives are to analyses of hydrological aspect designed to provide a large extent of data to implement Modern Irrigation Project that is expected to ensure the sustainable irrigation management and to make efficient use of water resources and thereby to sustain groundwater together with increase agricultural productivity in several irrigation sites in the Governorate of Hadramawt, thus to make people and water users particularly aware of the consequences of carless action toward water crises. Therefore, the overall objectives of Hadramawt Hydrological research study are as follows:

- The main objective of hydrological analysis is to provide sufficient data and information for the target areas in order to improve water management and increase irrigation efficiencies in the study area.
- Assess the extent of current groundwater situation in the aquifers of Hadramawt.
- Estimate the level of groundwater in relation to quantities of rainfall, surface runoff and annual recharge of the target aquifers.
- Analyze data with parameters relevant to water availability and consumption as well as water use and management for crops irrigation to be used in monitoring and evaluation before and after irrigation system implementation of modern irrigation.
- Provide a list of equipment and devices, which are needed to assist in carrying out the activities under the proposed project.
- Make recommendations for monitoring indicators related to water extraction rates in comparison with targets water saving.
- The result of hydrological analysis would suggest ways to reduce water consumption used for irrigation and improve water use efficiency particularly in critical basins of the target areas.

- Improve performance of assessment in water savings.

III. Methodology, Data Collection and Analysis:

Various methods of recharge estimation have been reported in the literature. The choice of a particular method depends on the type of data available. These methods can be summarized as:

1. Soil moisture balance method, which requires data on rainfall, runoff, evapotranspiration, soil moisture profile and other soil characteristics such as soil field capacity.
2. Modeling techniques in which rainfall, valleys/wadi discharge is included in the overall model. Reliable water level series for various observation wells are needed for model calibration in addition to other groundwater parameters.
3. Simple method in which the water level distribution in the aquifer, before and after the wet season are compared. Recharge can then be calculated as a function of the aquifer area, porosity or specific yield of the aquifer and the average rise in the water level.

If the average rise of water table is Delta H (m) and the aquifer area is A (km2) and the aquifer specific yield is Sy, then:

Volume of recharge is = A x Delta H x Sy x 106 m3/year

Since the lock of some data with respect to above parameters, another way is adopted for calculating groundwater recharge, abstraction and storage from the past estimates and trends taking into account the local conditions such as geological and topographic features and other controlling factors. Therefore, the formula used for valleys is adopted from the major regional aquifers and the regional ones from the aggregation order of the whole country for groundwater recharge, for groundwater abstraction and storage several techniques are adopted such as wells inventory, measured average capacity of groundwater pumped wells in terms of m3/hours/ha irrigated from groundwater as fallowing formulas demonstrate;

Volume of recharge is= A* (Rainfall (mm) /1000mm)*106 m3/year x Coefficient Factor).

(1)

Volume of recharge for specific basin is =(∑i-j ÷ Ai) x (Rainfall (mm) /1000mm)* 106 m3/year x Coefficient Factor)

(2)

Vol. of Abstraction is\=Water Vol. required for irrigation (m3/ha)* Irrigated area (ha).

(3)

Another way to calculate ground water abstraction is to determine the number of wells and their capacity of pumping in (m3 / hours) for each crop requirement of water during the growing seasons multiplied by area of concerned irrigated crop from groundwater as fallows;

Volume of water abstraction is = Average hours of pumping of water * Capacity of pumping in (m3/ hours) * Scheduled irrigation (m3 / hours* irrigation frequency)*Size of area of specific irrigated crops in concerned project.

(4)

Verification of these analytic methods is proved reliable on grounds that such analysis are based on gauged runoff parameters on the one hand, and on field measurement of water pumped from wells on other hand, as well as measurement of water volume used for certain irrigated crops during its full growing season carried on field units survey by GWSCP, 2007-2009. Furthermore verifying formulas are used to test the accuracy of the results of these estimates as fallows:

1. Estimated runoff and recharge volumes should be or nearly equals:

Mean Annual Rainfall (mm) ÷ 1000(m3)*Area*coefficient factor= the Runoff and recharge volumes of gauged catchments/valleys/basins respectively.

2. Estimated water abstraction should be or nearly equals:

Number of wells in concerned area * Average capacity of pumped wells (m3/ hours) multiplied by the aggregated area of irrigated crop in terms of (m3/ hours/ ha)

Methodology used in this research includes the following tools and techniques:

- Review of secondary sources including statistics, records, reports and references
- Direct observations during site visits.

- Conducting direct interview and discussions meeting method with individual and groups of stakeholders in target areas.
- Questionnaire was designed and distributed to collect data related to study in various issues related to wells pumping and irrigation use of underground water.

Data collection from both sources, the primary and secondary data of large scale were gathered, arranged, further tabulated, and analyzed by the team of experts assisted by the local enumerators, based on the statistical tools of analysis and application of models are used to make accurate estimation of groundwater recharge and discharge. Long range Final draft report on MIPs was prepared. With the help of MAI, GDFI comments on the draft, the Final Report was prepared and developed by the researcher and was submitted at the end of year 2010. Update and specific modification based on reviews conducted by the Judgment Team of Al-Razi University Journal for Medical Sciences (RUJMS) in June 2022.

The following methods related to the way how samples selection are chosen and adopted in response to the scope of work and successfully complete the outlined tasks within the prescribed and adopted time frame.

a. Sample Area Selection:

Selection of sample at the first stage involved a preparation of systematic list for all groundwater and wells pupping users in each wadi/ or Muderiah collected from the Agriculture Well Survey and Census. The next stage this data was arranged and stratified into categories according to their locations, in respect of existing pumping wells and groundwater irrigation areas. This selection method is accounted for 9 villages in 9 districts (ii) Representative villages of pumped groundwater (iii) Representative villages of grown crops pattern. The final procedure was to choose three villages from each of these three categories. This process ends with selection of groundwater users representing each project area, which considered collectively for the whole targeted area of the research study. Consequently, nine Districts in Hadramawt were selected from Hadramawt Governorate covering the project areas and another set of water units groups were selected from each project area in the concerned Governorate corresponds to the number of districts in the Governorate covering the main project areas. The study sample area covers 11 District, they are Alharga-Harad, Algar-Abs, Qazan-Abs, Algar-

Abs, Qazan-Abs, Alhgawrah-Hrd, Hiran, Banialhadad-H, Algar-Abs, Alhgawrah-Hrd and Hiran.

b. Selection of Water Users and Households Sample:

Selection process of households sample in this study consist of a list includes the total number of households in each of the selected area which were collected from the Agricultural Census, published in 2004, from this list a number of households were randomly selected for each sample representing the project areas in order to generate primary data in consistent with the approved household questionnaire. However, in a few cases some of the households were not readily available for providing the information as needed and in some cases the sharecroppers did not want to face the interview and has the opinion that this may hostile the relation between the sharecropper & landowner. Therefore, in such cases, those households were replaced by the available respondents, who were ready to cooperate with the survey. Around 17 farmers from each target project were selected. Finally, average of 15-17 farmers from each project area was interviewed. This makes a total of over 200 samples of farmers from all district of the governorate as a representative sample of households, which were selected for this study.

c. Review and Analysis of Available Data

During the initial stage of the study, it was of prime importance that all relevant available data and reports concerning the Groundwater Irrigation Improvement as well as the Government policy documents are evaluated. Thus, all available data and reports were collected from different primary and secondary source, in addition to relevant maps, drawings, reports and publications. The Review of literature includes large volume of data in geography, geology, hydrology (catchment areas, runoff, and floods) and metrology, climatology (rainfall, maximum & minimum temperature, relative humidity, sunshine hours, radiation, evaporation, evapo-transpiration, soil quality and moisture)as well as water resources availability (availability of surface water, groundwater from aquifer layers, rate of abstraction, depletion of groundwater, recharge, pumping wells and water balance) and in geomorphology aspects. Consequently, tabulation based data analysis and treatment were developed and presented in consist manner using suitable statistical data tools such as averages, means, standard deviation from the mean, coefficient, data extrapolation in based on historical/temporal trends and on spatial context developments.

In summary, the methodology used in this study includes several techniques: Review of secondary sources including statistics, records, reports and references, Direct observations during site visits, Conducting physical measurement method to gauge streaming water flood, rainfall, surface runoff and estimating recharge, furthermore, questionnaire was designed to collect unavailable needed data related to the study various issues.

1. HYDROLOGICAL STUDY ANALYSIS:

The study of hydrology in Hadramawt is composed of seven main sections and each section includes many sub-sections. The first section deals with the background of the project; objectives, tasks assigned, and the hydrology work program to achieve the objectives of hydrological study. The second section discusses the geographical settings in terms of location and topographic feature of the site and situation of project area as it related to administrative division of the concerned governorate. The third section explains rainfall data collection and methods of analysis. Time series of rainfall are used to reveal rainfall pattern in the concerned area and examine its temporal and spatial distribution at annual, seasonal and monthly averages as well as its relations with relevant climatic and other meteorological data. The fourth section analyzes the components of water resources availability in order to assess the type and amount of water sources at the surface and underground level within regional and local aquifers. Catchment areas in relation to rainfall and runoff parameters are used to estimate groundwater recharge rates. Comparative analysis is performed to contrast water abstraction with recharge rate in order to establish a baseline defining critical basins within concerned governorate and main basins of targeted project areas. Components of groundwater system and water saving as a consequence of the implementation of the proposed project are discussed in section four. Section five has mostly dealt with the monitoring and evolutional aspects of the project. In this section the components of groundwater system, magnitude of water levels in the basins of project areas and evaluation of current water balance by defining the extent of groundwater availability and depletion at a district level. The magnitude of water balance is pictured and charted in a detailed map for the Hadramawt project, so as to better control and monitor groundwater use based on location and using sustainable management methods to reserve water resources within the context of tasks achievements and practicing water saving activities under the suggested programs for Hadramawt Modern Irrigation Projects (CT-MIP) to be implemented in the concerned area. A list of hydro and meteorological devices and equipment needs is developed to support monitoring and evolution processes of the project. The cost of required equipment and devices for monitoring purposes, its distribution over the first five years of project life as well as the economic and financial analysis are summarized in section six. Finally, concluding marks and researcher recommendations are abstracted in section.

1.1 Background of the Study Area:

Agriculture in Hadramawt has a significant effect on the local and on the country economy as it serves for foodstuffs and livelihood support. The majority of the population (up to 60%) lives in the rural areas and about 37% of them are employed in agriculture where traditional farming prevails. Almost over 90% of the total water consumption in Hadramawt governorate is used by irrigation sector, of which 62% depends on groundwater. This is envisaged to lead to over-abstraction of groundwater as it evident in the serious depletion of ground water levels.

Based on the Agricultural Census published in 2004, the number of pumping wells in Hadramawt reached around **7,865** wells. Ground water levels have dropped dramatically from 150 m to 300m, particularly, in the main valleys basins during the last 40 years; this depletion is equal to a yearly rate between 2 and 7 meters.

The overexploitation of water is associated with the numbers and capacity of pumped wells and large number of wells combined with continuous pumping is directly endangering groundwater resources in concerned areas. All urban and rural areas are directly affected and they suffer various negative consequences (Frederic Pleat 2006).

1.2 Geographical Settings:

2.2.1 Location and topographic features:

Extending from the cost of Arabian Sea and the Gulf of Aden to northern border with Saudi Arabia, Hadramawt governorate is located in the eastern region of the Yemeni Western Plateau. It is bordered by Aljawf, Mareb, and

Shabwah governorates from west and Almahrah Governorate from the east. It extends from the sea to the depth of about 400 km toward the northern interior land; the governorate has an area of 155,376 km2. It includes 30 administrative Districts.

In terms of regional setting, it is a part of eastern regions of the Yemeni Eastern Plateau. The elevation of the geographical region in which Hadramawt governorate is situated ranges from a few meters on the coastal area to more than 1,000 m. in the interior areas.

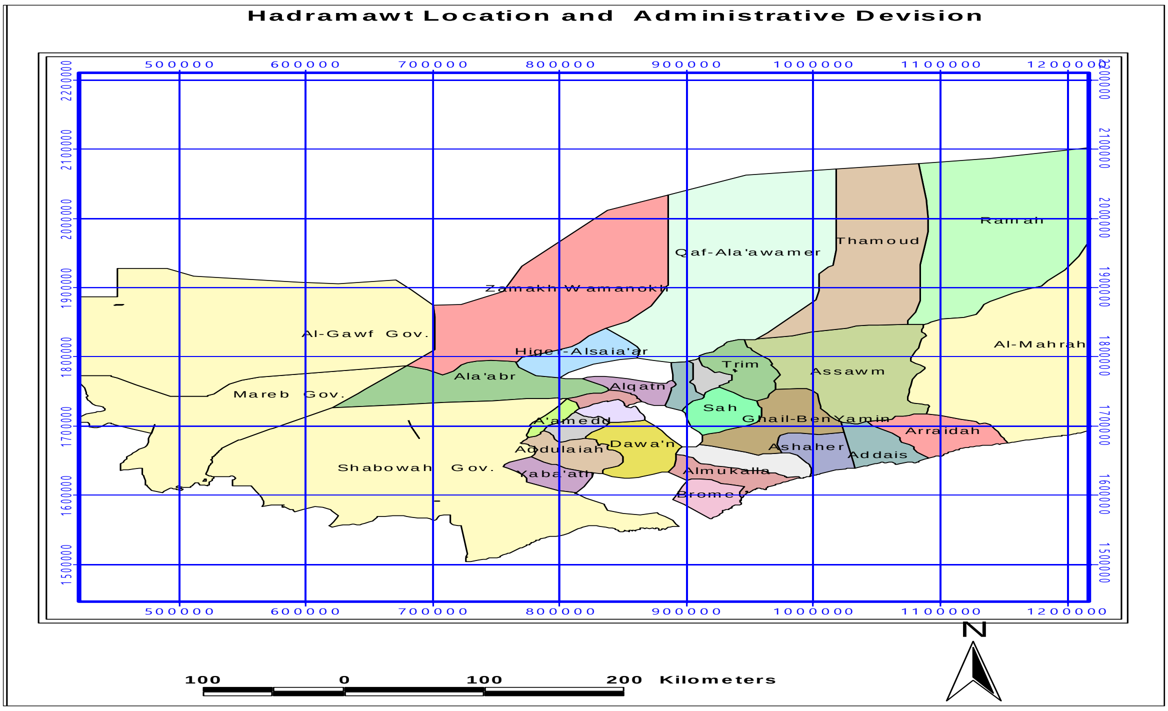
The soils in Hadramawt are generally medium textured, the best being in wadi Hadramawt. Like the areas of Lahej-Abyan plains, the areas of Hadramawt plains also contain important agricultural zones, due to numerous valleys namely: Wadi Amd/Doan, Wadi Al Ayn, Wadi Sarr, Wadi Bin Ali, Wadi Juaymah, Wadi Idim, Wadi Hajar, Wadi Mayfa'ah, and Wadi Thibi, in addition to some minor valleys flowing to the west and north of Hadramawt Governorate.

The hilly hinterland enables spate irrigation to be practiced. The valleys also provide recharge to the porous and permeable quaternary sedimentary aquifers of the plains. The area is composed of mixed old-modern alluvium from the valleys. Its topography is divided by limited rocky out crops areas, hills, and medium depth valleys run in north-south and east-west wards. Sand dunes are common in the interior and north areas. Also rocky and sandy cost is presented in southern zone of the governorate.

2.2.2 Administrative Division

Hadramawt Governorates consists of 30 Districts, the third order of administrative division of the country. As a geographical unit, Hadramawt does not have a distinctive boarder as much as being an administrative. The districts vary in climatic features and in area extent. Ramah, Thamoud, and Qaf-Ala'awamer, are the largest Districts in the governorate, occupy the western coastal area of the governorate. The other districts as they are labeled in the map (Figure 2.1-a) of Hadramawt: Zamakh Wamanokh, Higer-Alsaia'ar, Ala'abr, Alqatn, Shibam, Sah, Saya'own, Trim, Assawm, Arraidah, Addais, Ashaher, Ghail-BenYamin, Ghail-BaWazir, Almukalla, Dawa'n, Wadi-Ala'in, Rukhaiah, A'amedd, Addulaiah, Yaba'ath, Hagr, Brome, Hdibaw, Qalansiah, Huraidah

Figure 2.1-a: Location and Administrative Districts, Hadramawt Governorate



2.2.3 Classification and Description of Aquifers:

Mukalla Sandstone Aquifer is an extensive basin where thick strata of Mesozoic and Tertiary sediments have been deposited in the east of the shield and north of the Al Ghaydah basin and of the rifted zone along the Gulf of Aden. Further east, it probably directly overlies the Precambrian basement of this basin, indicated Zarubezhgeologia (1992) in WRAY-35, as the Tawilah Artesian basin¬ extends far northwards over the platform zone of the Arabian Peninsula.

Mukalla Sandstone averaging 300-400 m in thickness is widely present in this basin and forms a continuous regional aquifer of large side extent. Ramlat as Sabatayn zone in the western part rests upon Jurassic sediments, a thick series containing saline water, and with oil-bearing zones. In the Ramlat as Sabatayn it is overlain by Quaternary continental deposits, a few meters to more than 150 meters thick and probably largely unsaturated. In the Plateau Region it is capped by a thick sequence (around 300 m) of carbonate rocks of the Hadramawt Group.

The Mukalla Sandstones are reported to have a maximum thickness of approximately 1000 m in the Shabwah area; the underlying Jurassic deposits there are even thicker (around 3000 m). The sandstone strata dip in easterly to north-easterly directions; they are no longer of practical interest in the eastern part of the Plateau Zone, because of their great depth and a gradual transition to a less permeable marine facies. The related eastern boundary and also the southern boundary of the basin indicated were copied from Zarubezhgeologia (1992). The western boundary could be defined with reasonable accuracy on the basis of available geological maps and data presented by Yemen Hunt Oil Company (1993), Uil and Dufour (1990). Only its northern tip is uncertain: it was taken as the envelope of the Mukalla Sandstone outcrops visible on the geological maps.

Although the sandstones have not yet been sufficiently explored, it can already be stated that they constitute the largest groundwater system in Yemen, storing huge quantities of groundwater. The depth to the aquifer is modest under Quaternary deposits of the Ramlat as Sabatayn, but the aquifer horizons are generally at considerable depth in the Plateau area, especially in the southern and eastern part where they are generally at 300-400 m below ground surface. In deeply eroded wadi valleys they are locally exposed or at rather shallow depths below the wadi beds. This is e.g. the case in Wadi Hadramawt (see Figure 6.4), the only zone where massive abstraction from this extensive aquifer unit is currently taking place. Mukalla Sandstones outcrop over a large area in the western part of the Northern Plateau Zone (see Figure 2.3), but groundwater levels there are between 100 and 200 m deep (WRAY-35, 1995).

Al- Mukalla sandstones generally have high porosities (up to 25 % ?) and it is assumed that both pores and fissures contribute to groundwater flow. "The transmissivity of the sandstone aquifer is rated as high; in the Wadi Hadramawt area it has been shown to be variable, but values in the range of 3000 to 3500 m^2/day are not uncommon" ((Kazgiprovodkhoz, 1983)& (WRAY-35,1995), 1983, 1995)

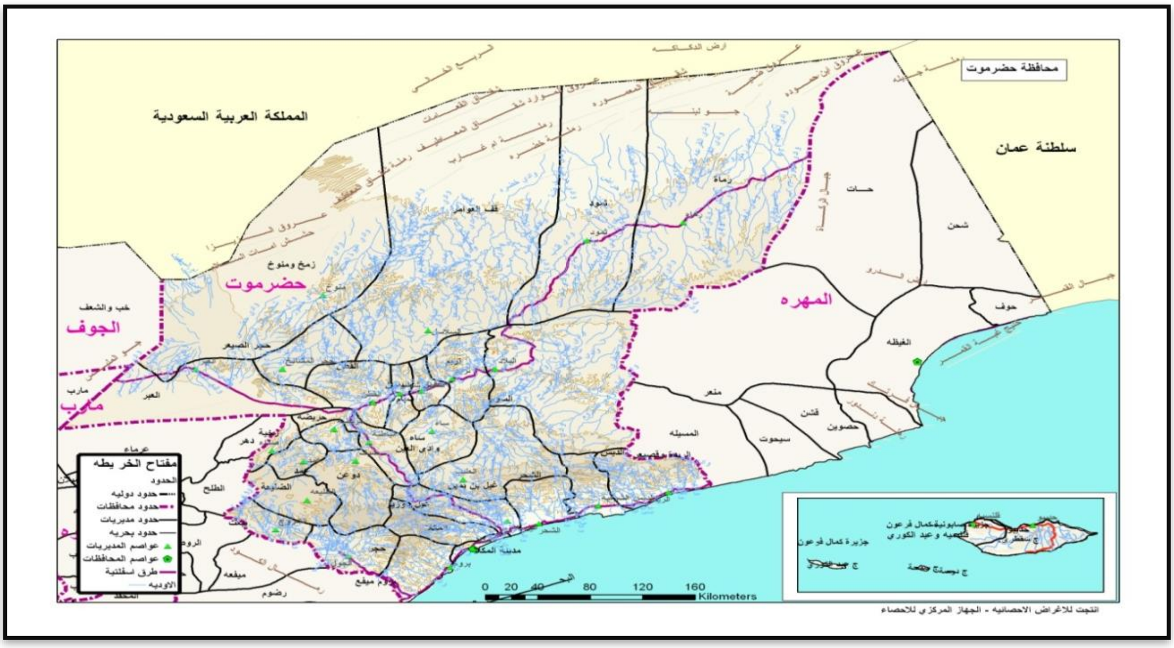
Almukala aquifer is one of the largest aquifers in Yemen. the slopes goes (i) from the coast up to 11 km inland was categorized as “Low Hazard Category”; (ii) between 11 to 16 kms from the coast was categorized as “Middle Hazard Category”; and (iii) between 16 kms from the coast up to the NW edge was categorized as “Highest Hazard Category” as the groundwater depletion in this belt ranges from 3 to 6 m/year or more.

Hadramawt Group form an extensive and almost continuous cover in the eastern half of the country. These geological formations are referred to the

Paleocene/Eocene epoch The group is transpose from east to west over the Cretaceous Tawilah Group and composes of shallow-water limestones, shales, marls and evaporates. Hadramawt Group is present. Younger formations of the group cover east most and northward areas with gypsiferous conglomerates and sandstones materials. They could be in principle grouped under the Hadramawt Group, which would then extend into the Oligocene (Robertson, 1991 and WRAY-35). The rocks of the *Yemen Volcanic* form a large and nearly continuous plateau in the western part of Yemen. The average depth of the volcanic series is around 2000 m. The sequence consists of sub-horizontal strata of basic to acidic lavas, ignimbrites and pyro clasts, with intercalated soil upperparts. Previous geological studies suggest a subdivision into four parts, goes from bottom to top these are: (a) a melanocratic Basal Series; (b) the well-bedded Haddah Series; (c) the heterogeneous Chaotic Series; and (d) a well-organized Upper Series. The latter two series are mainly observed in the eastern marginal zone of the Red Sea graben (WRAY-35, 1995).

Most of the governorate area lies down on sedimentary deposits and quaternary depressions. The site is generally a flatten plain region except for some hells, slopes, particularly in the northeastern parts of the governorate. ((Kazgiprovodkhoz, 1983)& (WRAY-35,1995), 1983, 1995)

Figure 2.1-a: Main Valleys and Watersheds, Hadramawt Governorate



2. CLIMATE:

Climate of Hadramawt as reviewed in the literature is hot and arid climate. Further inland over wadi Bana catchment, the climate becomes semi-arid. The rainfall, in general, is low to very low varying from 50 mm in the lower parts in the south to 200 mm in the upper parts in the north, with an average annual rainfall of 65 mm at Al-Kod and 35 mm at Ja'ar areas. The annual rainfall vary between 50-125 mm/year, most of which occurs in July-December. Mean monthly maximum temperatures range from 28^0 to 40^0 in cold season (November – January), while the hot season is ranged between 40^0 to 43^0 C. The altitude ranged between 700-1000 m. Climate is discussed in details in the next sections.

Based on Saya'un station, the dominant climate in the governorate can be classified as hot-arid in the coastal areas and semi-arid in areas of higher elevations. Rainfall analysis for 36 years since 1972 shows that the mean of annual rainfall is about 62 mm/year, 49 % falls in spring and 39% in the summer season. The average monthly maximum temperature is 36.3^0 and the minimum is 17.7^0 C. The region is characterized by low humidity (average RH is 49% in Jan to 31 in June %). The average number of Sunshine hours ranges 8-10 hr/day, in rainy season decreased down to 7-8 hr/day.

Rainfall data analysis is described under the following section. Rainfall patterns, spatial and temporal rainfall distribution and metrological data such as temperature, relative humidity, wind velocity, sunshine and, evapotranspiratation are discussed at the end of the climate section.

Due to its location in southern part of central highland, the governorate topography forms parts of Highlands and high plateau. Rainfall here is characterized as much similar to that of highland regions and rainfall of western slopes. Mean annual precipitation is moderately variable both in time and in space, being strongly affected by inter-annual variations and by altitudes. The rainfall is slightly adequate to produce rain-fed crops, in valleys and plains of the governorate, consisting largely of cereal grains cultivation. In addition, fruits and vegetables are also produced.

2.1 Rainfall Data

There are only one rainfall stations in Hadramawt with continuous long records of over 20 years, even though some records in the series have several interruptions. For the purpose of this investigation, mean annual rainfall data have been collected from various sources for stations representing the governorates for at least the period (1972 – 2008). The data have been updated to include more recent years. The available data has been analyzed to reveal the general rainfall pattern as well as the temporal and spatial variations of rainfall over the governorate and its districts where the MIP well be sited. The following sections discuss the rainfall pattern, temporal and spatial variations of rainfall in Hadramawt Governorate where the project of modern irrigation takes place (MIP) and is to be developed.

2.2 Rainfall Pattern

Rain is the main form of precipitation in Hadramawt Governorate, but hail is not uncommon near the mountain slope area. Rain storms are dominantly convective in the region. As a result, their areal extent tends to be limited, in spite of the fact that the general circulation that sets the general conditions for the occurrence of rainfall is of a sub-regional scale. During summer periods of intensive convergence of trade winds, several rain storms may develop, bringing rainfall to extensive areas of highland. But in Hadramawt plains, there is a regional great difference in the amounts of rainfall over short distances. The general observation for most individual storms is that they cover only a limited area, no more than several tens of square kilometers. Local effects are strongly controlling the spatial patterns of rainfall in the different regions of Yemen. The location effect of the governorate facing the Gulf of Aden and Arabian Sea from the south is significantly present in the air moisture and rainstorms in a few occasions; however, the effect of dryness of the interior appears on the evapotranspiration extent and on the soil impacts.

Table 2.1 illustrates the mean annual rainfall of Hadramawt during the last 36 years since 1972. The time series has some incomplete records (first 4 years). Data analysis of the rainfall series is based on observations of *Saya'wn* station. The annual rainfall mean in the first 12 years is about 57 mm/year, with variation of 16.5 mm/yr. The mean of annual rainfall during the second decade is 65.6 mm/year or about 20% higher than previous decade, but the mean retreated to 60 mm/year during the last decade. Variation of the rainfall mean through the three mentioned period is partly attributable to spatial differences and partially to incomplete records at the beginning and the end of time series (4 and 3 years), which they are extrapolated using regression trend. A gradual increase in rainfall average can be noted in the second decade over the first and last decades, but with wide variation as is compared to the other decades.

The overall mean of rainfall series is around 62 mm/year, nearly 25-30% of the rainfall amount falls on the highland of the Plateau. The average deviation from the mean for the series is 16 mm/year. Unlike the central highlands, the lowland of coastal plains and interior areas implies that a correlation coefficient between rainfall amount and variation extent in temporal as well as in spatial terms is significant for less dry areas, indicating to a changeable effects from local to regional factors impacting such relations. It is predictable from the past trend that a lower average of rainfall tends to occur once every 3-5 years as it is noted in the histogram in figure 2.2. The inter-decadal rainfall variation as ups-downs departure from the mean is 24 mm/year, and it is wider than that of inter-annual variation that is 16 mm/yr. as noted from the table.

Table 2.1 Annual Rainfall Pattern, Hadramawt 1972-2007

Year	**Rainfall (mm/yr)**	**Year**	**Rainfall (mm/yr)**	**Yea r**	**Rainfall (mm/yr)**	**Total 1972-2007**	
						Average	**Deviation**
1972	59.3	**1984**	22.3	**1996**	86.7	56	23
1973	58.6	**1985**	9	**1997**	86.2	51	28
1974	57.0	**1986**	68	**1998**	39.6	55	10
1975	56.0	**1987**	110.3	**1999**	111.5	93	24
1976	55.1	**1988**	8.4	**2000**	22.7	29	18
1977	13.3	**1989**	175.6	**2001**	76.4	88	58
1978	12.4	**1990**	72.7	**2002**	76.6	54	28
1979	31.1	**1991**	44.0	**2003**	32.3	36	5
1980	53.3	**1992**	74.2	**2004**	34.8	54	13
1981	56.0	**1993**	80.9	**2005**	53.5	63	12
1982	125.0	**1994**	30.4	**2006**	51.0	69	37
1983	109.0	**1995**	127.7	**2007**	48.5	95	31
Mean	**57.0**		**68.6**		**60.0**	**62**	**24**
D.F.M	**16.5**		**38.3**		**22.9**	**16**	**11**

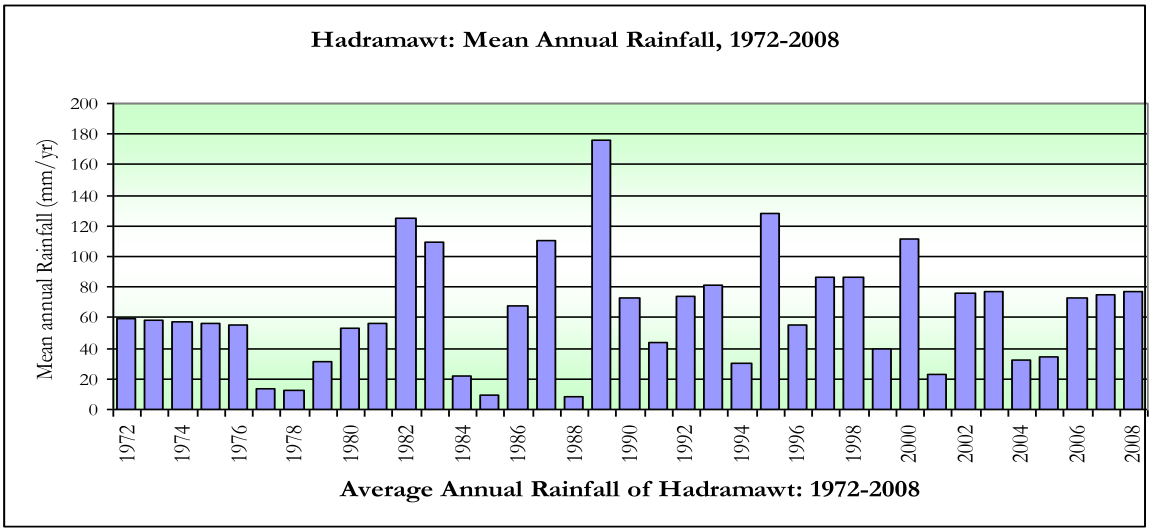
Note: Data from 1972-76 and from 2005-2008 are extrapolated. (unavailable)

Sources: Agro-Climate in Yemen General Authority of Agricultural Research and Guidance, Hadramawt Center,2005

MAI, Yemen Irrigation Improvement Project, Hydrological Analysis-F. Report, October,2003

MAI, GDOS, Agricultural Year Book Statistics, 2003-2009 (MAI, 2002, 2003, 2004, ...,2009)

Figure 2.2: Annual Rainfall Pattern, Hadramawt 1972-2008



Source: Table 3.1

It is clear from the histogram that there are low averages in the rainfall pattern that occur almost every 4-5 years in the series while years of rainfall above the annual mean do not conform to specific pattern of rainfall. Therefore, rainfall threshold is indefinite in the case of Hadramawt climate. Any significant deviation is most probably attributed to the spatial variations where a rainfall record of Saya'wn City is insufficient gauging to generalize the result for over all areas in the governorate.

2.3 Temporal Variations of Annual Rainfall

Annual rainfall mean varies from year to year and from location to location even in the same region or governorate. Table 2-1 shows the distribution of annual rainfall in the governorate for 35-year period (1972-2008). Some rainfall records for Saya'wn station are missing and the series is cut-off, which makes it difficult to study temporal rainfall trend with high validity. However, the analysis of Saya'wn rainfall station records has relatively long series of nearly complete observations as the few missing rainfall records is extrapolated which allow studying temporal variation with some certainty.

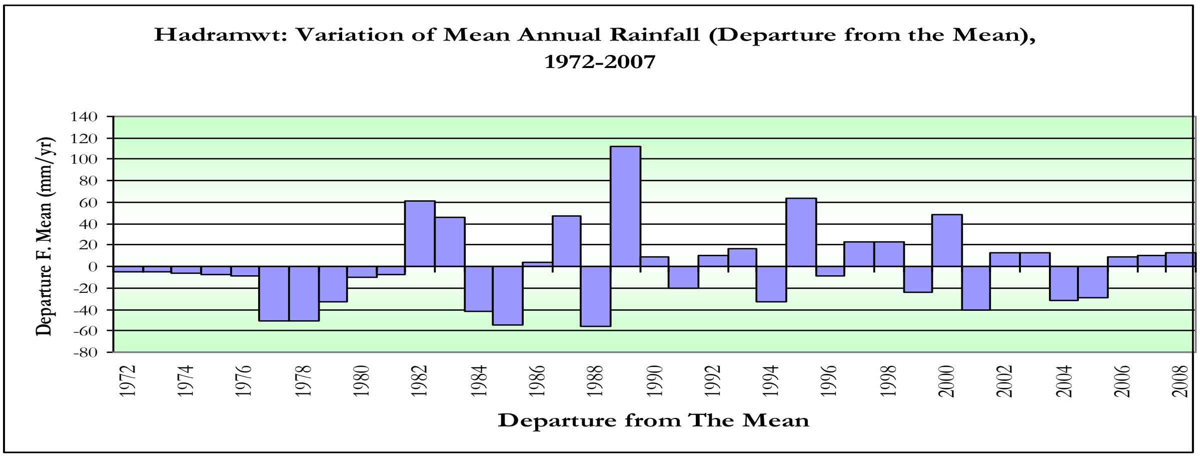
Analysis of the rainfall observations reveals that the long time series has a rainfall average total of 62 mm/year, with a total variation of 16 mm/year. The annual coefficient of variation is 0.246 and rainfall mean of the second decade is inversely related to that of the second and last decade as higher means are presented in this decade.

In spite of some missing data (5 years) the series is suitable for the analysis of rainfall variations at Hadramawt for at least a half of a century. Unavailable records are statistically extrapolated using linear and regression models.

The variation about the mean ('departures from the mean') enable to draw some conclusions. The most important is that there is significant long-term trend where at least each couples of years vary significantly from the succeeding or preceding years as it shown in Figure 2.3, the variation around the mean. In general the most variable years in rainfall means are those of mid-eighties and the early of nighttime.

The coefficient of variation of the annual rainfall series tends to increase with increasing rainfall average and vice versa. This means that variation from year to year is equally pronounced at either wet or arid sites, at least in relation to the average rainfall. This consistency usually characterizes semi-arid and dry locations

Figure 2.3: Rainfall Variation about the mean, Hadramawt:1972-2008



Source: Table 2.1

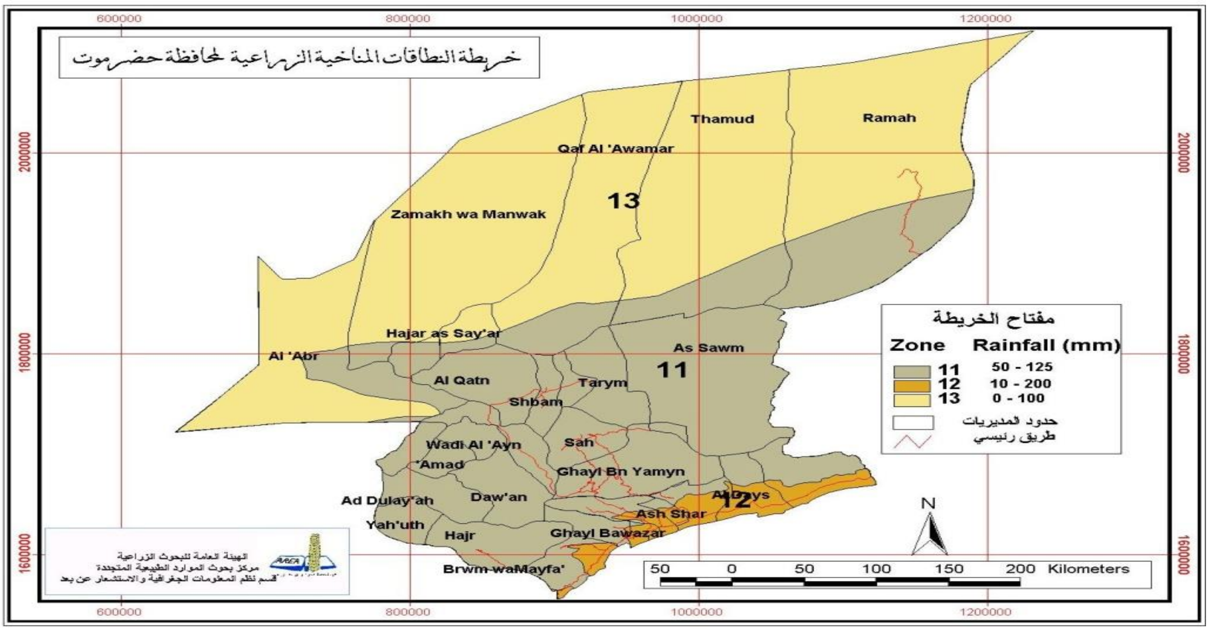
2.4 Spatial Variations of Annual Rainfall:

The spatial pattern of annual rainfall can be glanced through the isohyets-map of spatial distribution published by MAI, GWSCP. The controlling topographic factors, however, are strong enough to make distinct patterns that are fairly stable for long-term averages of annual rainfall. Figure (2.3) of agro-climate and associated table key shows the spatial pattern distribution of average annual rainfall mapped in Hadramawt governorate during the period 1983 through 2003. This standard period was chosen as the period for which as many rainfall stations as possible have nearly complete records and scattered all over the governorate.

There are three distinctive agro-climate zones in Hadramawt governorate, indicating a spatial rainfall pattern there. The Isohyets Agro-Climate Zone map (figure 2.4) for the governorate was developed by the General Authority of Agriculture Research (GAAR). It provides a clear and consistent picture of the spatial distribution of annual rainfall over all districts even with many associated constrains.

The general distribution of rainfall zones takes a sector-like distribution of three E-W striped zones along the eat-west axes. The first zone with annual rainfall 10-200 mm/year covers the coastal area with 30 km. in width extending in parallel to the coast line. It is very narrow strip as is compared to the other two zones. The second rainfall zone with depth of about 250 km northward has an annual rainfall of 50-125 mm/year. It dominates the most central areas of the governorate. The third zone of annual rainfall mean less than 100 mm/year is found in northern half of the governorate, particularly in Ramah, Thamoud, Qaf-Ala'awamer, and Zamakh Wamanokh Districts as Figure 2.4 and 2.5 describes.

Figure 2-4: Spatial Rainfall Distribution, Hadramawt Governorate



Source: The General Authority of Agricultural Research, MAI, Hadramawt Center, 2009

2.5 Seasonal rainfall pattern

Hadramawt governorate demonstrates a two well-defined seasonal rainfall pattern as is shown in the line-graph below in figure 2.5. Based on 35 years of rainfall observation (1972-2007), two rainfall seasons are clearly dominant in the distribution pattern. The first rainy season occurs in spring (March-June) with seasonal mean of 32 mm/year, representing 49 % of total annual rainfall and the second one occurs in summer (June-October) with rainfall mean of 25 mm/season, representing 39 % of the total annual rainfall. The highest monthly rainfall mean occurs in March with nearly 14 mm/month. However, Decembers is the driest month in the year receives less than 1 mm. The correlation coefficient of variation between the two seasons is 0.81 indicating to a well-defined seasonal pattern with consistent rainfall distribution.

Figure 2.5 present monthly rainfalls in Hadramawt governorate and figure 2.6 compares monthly rainfall distribution with monthly averages of relative humidity and evapotranspiration.

Figure 2.5: Seasonal rainfall pattern, Hadramawt: 1972-2007

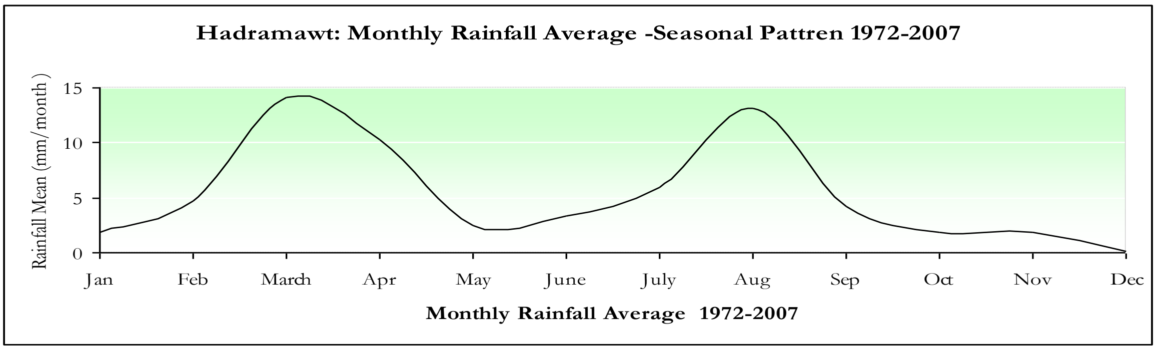
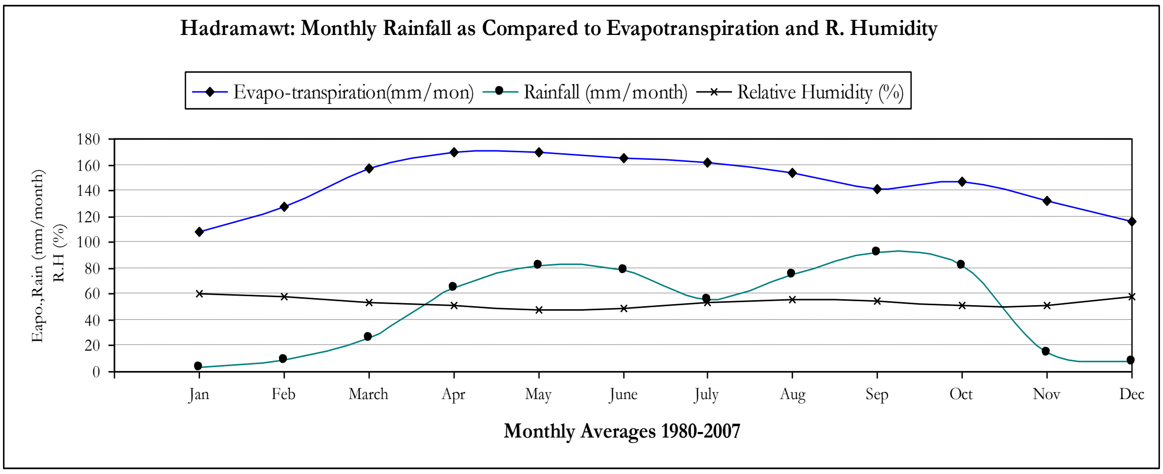


Figure 2.6: Monthly rainfall pattern as compared to relative humidity and Evapotranspiration, Hadramawt 1983-2003



Source: - The General Authority for Research and Agriculture Awareness, Guidelines of Agro-Climate in Yemen 1881-2004, 2005

The interchangeable effects of climatic factors explain the extent of rainfall influence on and by those factors. The correlation coefficient between monthly rainfall and evapotranspiration is -0.378, inverse relation indicating that more rainfall influences evapotranspiration through its impact on temperature as they correlation explains more than 40% of occurrences. As a matter of fact the mean of monthly rainfall is inversely associated (-0.599) with relative humidity, as higher rainfall average decreases the capacity of relative humidity through cooling down the air temperature as shown in figure 2.6.

3. METEOROLOGIAL DATA ANALYSIS:

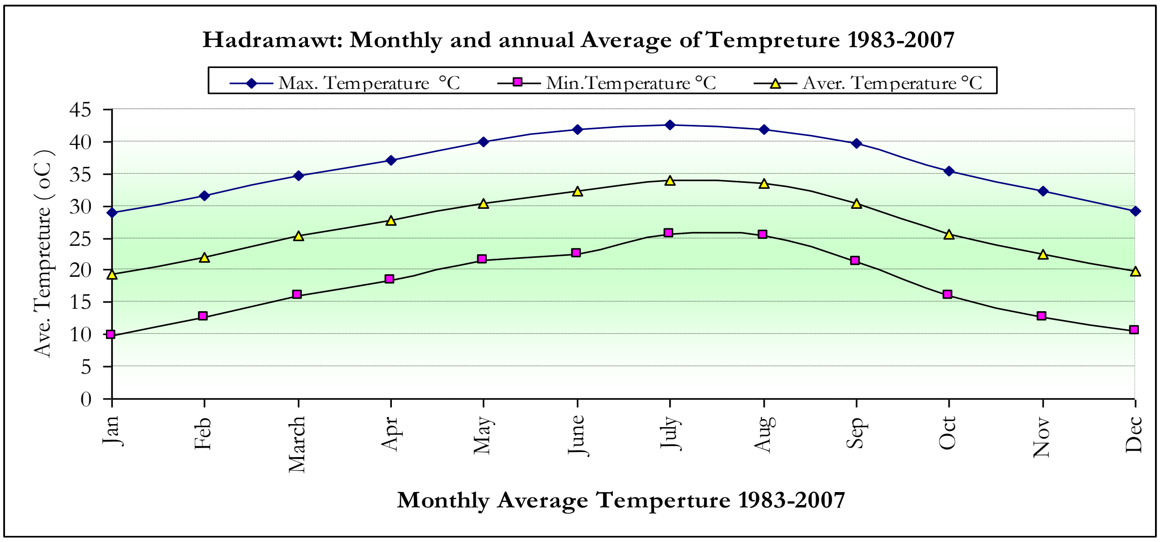
Meteorological variables other than rainfall are observed at most of the meteorological stations in Yemen. These are daily sunshine duration, temperature, relative humidity of the air and wind velocity. Average monthly values for these variables for Hadramawt from 1983 to 2008 are shown in Table (2.3).

The accuracy and reliability of these meteorological data may be uncertain for part of the records. Careful checks and verification of quality assessments are certainly performed in order to get an accurate analysis results.

3.1Temperature:

The average monthly temperature of Hadramawt governorate is 26.9 °C, ranges from a minimum of less than 10 ˚C in January to a maximum of 42 ˚C in June and July. Figure 2.7 shows line-graph presentation of monthly averages of temperature along with maximum and minimum averages. A strong spatial variation associated with elevation and distance from the coastal to interior areas of the governorate.

Figure 2.7: Monthly Temperature, Hadramawt Governorate 1983-2007



3.2 Relative Humidity:

Temporal and spatial variations in relative air humidity are insignificant at annual level (37.7 %), but it is pronounced at monthly averages in the value ranges of minimum 23 % in June to maximum of 48 % in December as Table 3.3 and associated figures describe.

Table 2.3: Meteorological data, Hadramawt Governorate 1983-2008

Meteor-Climatic Variables	Jan	Feb	March	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Average
Max. Temperature	28.9	31.6	34.7	37	40	42	42.5	41.9	39.7	35.4	32.4	29.3	36.3

°C													
Min. Temperature °C	9.8	12.7	16	18.5	21.6	22.6	25.6	25.4	21.3	16	12.6	10.5	17.7
Aver. Temperature °C	19.3	22.1	25.3	27.8	30.3	32.3	34	33.6	30.5	25.7	22.5	19.9	26.9
Relative Humidity (%)	49	47	23.3	39	33	31	32	34	35	39	42	48	37.7
Wind Speed (m/sec.)	0.7	0.8	1	1	1	0.9	1.1	1	0.8	0.9	0.6	0.6	0.9
Sunshine (hour/day)	8.4	8.7	8.6	8.9	9.7	8.7	7.9	8.1	8.8	9.1	8.9	8.6	8.7
Rainfall (mm/month)	1.9	4.7	14.1	10.3	2.5	3.3	6	13.2	4.2	1.9	1.8	0.1	5.3
Evapotranspiration-.(mm/mon)	95	121	15	173	187	191	206	199	169	139	104	189	207

Sources: MAI, General Authority of Agriculture Research in Yemen, 18881-2004, Hadramawt Research Center, 2005

Ministry of Agriculture and Irrigation, 2003 Year Book Statistics, 2004 and 2008 Year Book Statistics, 2009

MAI, Final Report, Indian Consultant, 2006

Sources: Agro-Climate in Yemen General Authority of Agricultural Research and Guidance, Hadramawt Center, 2005

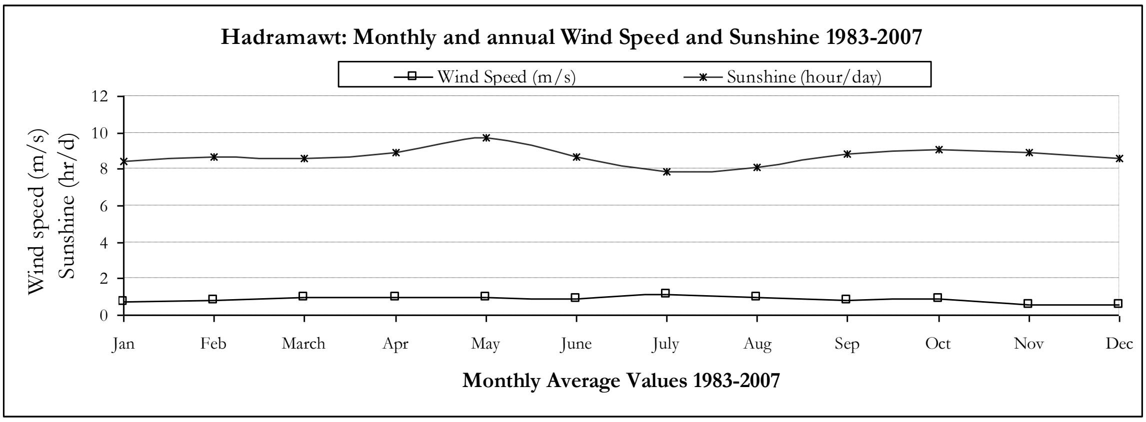
3.3 Sunshine:

The records of sunshine duration shows that clear skies are predominant in Hadramawt Governorate during most of the year. The monthly average values of sunshine in the Governorate ranges from 7.9 hours a day in July to 8.9 hours per day in April and Novembers which corresponds to 55 -75% of the theoretical maximum. Absence of sunshine during daytime is not only affected by clouds, but also mountains near the site of observation may also shorten sunshine duration because of the shadows they produce after sunrise and before sunset.

3.4 Wind Speed:

The average wind speed in most of Yemen ranges from low to moderate, except on the coast and at well exposed locations in the mountain zones. It is believed that a significant part of the differences has to be attributed to local effects. Figure 2.8 illustrates monthly wind speed as meter per second along with sunshine curve. The average monthly wind speed in Hadramawt ranges from less than 0.6 meter per second in winter months to 1.1 m/s in the months of spring. The annual average of wind speed is 0.9 m/s as is seen in the line graph as constant due to insignificant differences.

Figure 2.8: Monthly Sunshine and wind speed, Hadramawt Governorate 1980-2007



3.5 Evapotranspiration:

The potential evaporation and evapotranspiration records in the Metrological table for Hadramawt during the period (1983-2003) shows that the annual average is 2484 mm and the monthly average ranges from a minimum of about 95 mm/month in January to a maximum of around 191 mm in July, which is almost at a comparable range of that of western coastal area of Tehama in Alhodaiedah. The annual average is 2487 mm/year. Figure 2.9 compares monthly evapotranspiration in the governorate. Figure 2.10 also compares Hadramawt with the other governorates in the country with respect to annual evapotranspiration.

Figure 2.9: Monthly Evapotranspiration, Hadramawt Governorate

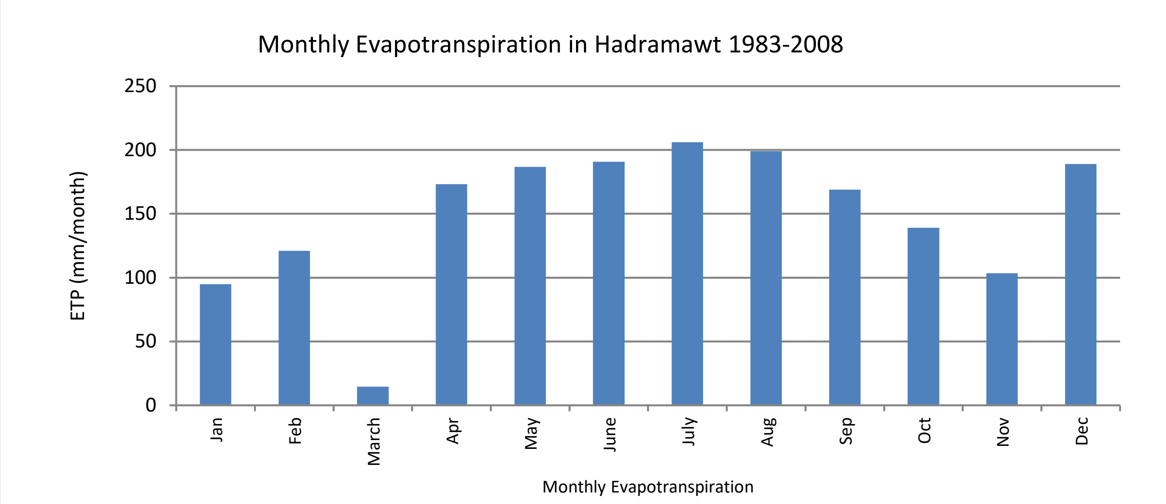
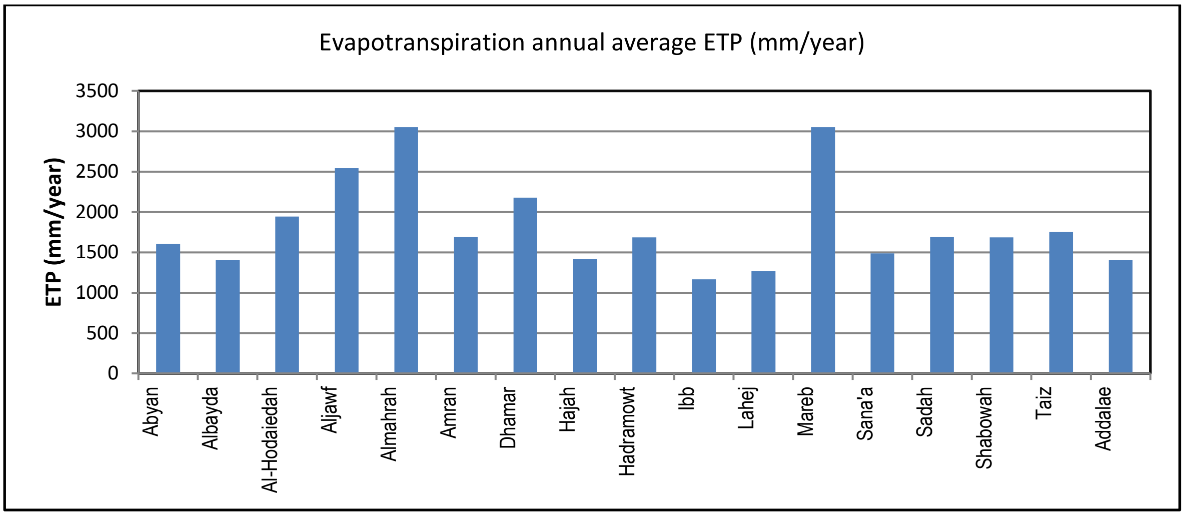


Figure 2.10: Annual Average Evapotranspiration at Project Locations (comparison)



4. WATER RESOURCES ASSESSMENT:

Due to insufficient rain-fed agriculture, many areas depend on groundwater for supplement irrigation by overexploitation of deep aquifers, which are consequently in depletion of groundwater table.

Several Parameters are used to assess water availability. The most important are means of annual rainfall in catchment producing areas and in absorbing areas for considerable time span, runoff and recharge volumes in mm/year and in MCM/year, number of pumped wells and their mechanical capacities in terms of m ^{3}/ hours of water discharge. Other variables are also employed such as water level in a basin and water application for irrigated crops according to traditional versus modern use for all types of cropping pattern. Data of water applications amount in m^3 per crop type for each hectare of irrigated Field Units by GWSCP proved to be reliable as compared to the number of active wells and their capacity of pumping and drops in water tables in concerned areas and basins. Irrigated areas from groundwater were measured in 18 Field Units covering 18 Yemeni Governorates.

Methods of data analysis include statistical models, historical linear regression trends and forward extrapolation in addition to verifying formulas in order to test validity of data analysis. Data input of these parameters and related variables are organized and tabulated analytically and aggregately according to three spatial levels: first, at regional and local levels, then, at basin and wadi levels, and finally at districts and governorates or administrative division levels.

The purpose of these geographical partitions is to enable concerned authorities to functionally plan, manage and control water resource and guide project implementation process properly with clear advisory and sustainable work bases.

4.1 Surface Water and Runoff Scale

The runoff process is controlled by several factors; considering the conditions encountered in Yemen, the main factors are:

(a) Size and shape of the catchment;
(b) Rainfall characteristics, such as intensity, spatial and temporal distribution of rainfall;
(c) Rates of potential evaporation and evapotranspiration;
(d) Terrain characteristics of the catchment area such as slopes; properties of soils, rock outcrops and vegetation;
(e) Presence and properties of regional groundwater systems;
(f) Land use and other human interference.

Table 2.3 gives an explanation of the distribution of runoff producing and runoff absorbing zones over the territories of Hadramawt Governorate. The runoff producing zones are subdivided into zones with a permeable surface and those where outcropping rocks are more or less impermeable. Relevant data has been updated and some other catchment areas of highland region and division by governorate and its territories are added to the model. Certain modification of runoff coefficient values is carefully rearranged in relation to topographic features and soil coverage based on mean annual rainfall figures aggregation and relative areal extent representation. This may be of interest for better understanding the differences in runoff regimes; the aggregation level of the map did not allow other relevant terrain features to be incorporated, such as terrain slope and presence of vegetation and terraced agriculture, which is recommended to be investigated and covered in future projects. Previous reports provided some estimation for both surface and groundwater "runoff and recharge" which has been incorporated in the current estimation of this study. The basic estimation analysis of surface and groundwater in the current hydrological study for Hadramawt has been performed using various models. Careful check and examination also has been done to test the validity of analysis and the results are shown below in table 2.3.

Hadramawt basins and valleys are presented in table 2.3. There are 11 sub-basins of which 9 would be nominated as sites for project locations in Hadramawt. The selection process assumed suitable sites for the implementation of irrigation improvement project. The valleys listed in the table are examples of runoff catchments and absorbing zone in the governorate. In fact, they are insignificant as runoff producing zones due to the low average of rainfall, but they are important areas as absorbing zones in the governorate.

The total area of the runoff catchment areas covering is 39,275 sq. km. These catchments produce 186 MCM/year as runoff water in 2008. About 90 % of this amount accounts for recharge rate which corresponds to 151 MCM/year as a renewable source of groundwater that is absorbed contributing to the aquifers recharge in Hadramawt governorate as shown in table 2.3 below.

The summary table demonstrates the catchment area, mean annual rainfall in mm and in MCM, runoff volumes in million cubic meters, and runoff coefficient in addition to recharge estimate.

Table 2.3: Mean Annual Runoff for runoff producing catchments, Hadramawt Basins

Project name	Southern Coastal Plains& N. Plains	Catch ment Area	Mean Annual Rainfall		Mean annual runoff				Recharge Volume	
			(82-2008=28yr)		(1980-2008)					
	ARABIAN SEA BASINS	(Km2)	(mm/yr)	(Mm3/yr)	2008 (mm/yr)	2008 (Mm3/yr)	1984 (Mm3/yr)	1994 (Mm3/yr)	2008 (mm/yr)	2008 (Mm3/yr)
Coefficient Values					**0.608**	**0.608**	**gauged**	**0.0539**	**0.904**	**0.904**
Hadramawt	Wadi Amd/Doan	6550	80	524	5	32	20	25	4.4	29
	Wadi Al Ayn	1500	75	113	5	7	10	8	4.1	6
	Wadi Sarr	2540	45	114	3	7	3	4	2.5	6
	Wadi Bin Ali	720	65	47	4	3	2	3	3.6	3
	Wadi Juaymah	760	35	27	2	2	1	1	1.9	1
	Wadi Idim	5485	70	364	4	23	41	30	3.8	21
	Wadi Hajar	9900	100	990	6	57	x	54	4.0	40
	Wadi Mayfa'ah	4300	100	430	6	25	x	24	4.0	17
	Wadi Thibi	720	40	29	2	2	2	2	2.2	2
	Minor valleys w.	3000	100	300	6	18	x	17	5.5	16
	Minor Hadr. Tributaries	3800	45	171	3	10	x	9	2.5	9
	Total Area 155,376 km^2	***39,275***	***69***	***3128***	***4***	***186***	***79***	***177***	***4***	***151***

Note: Mean annual rainfall is referred to the average catchment producing areas while recharge is referred to absorbing areas

Sources: Ministry of Agriculture and Irrigation Compiled from different tables presented in "Water Resources, Report-35, 1996". The Table is compiled from various sources

The assessment table of runoff and recharge water has three cell-fields of runoff volumes of which two of them are assigned to the estimates of previous studies in 1984 and 1994. Compression of the runoff figures in three decade shows that a strange association is present among the three estimates but the correlation coefficient between 1994 and 2008 estimates is stronger 0.981 versus 0.797 with the gauged catchment estimation of 1984. Despite the consistent methodology and valid analysis adopted by these estimates, variations in runoff assessments could be attributed mainly to some unavailable data related to 1984 estimation and partially to the independent variable of the runoff coefficient values.

The volumes of stream flow per km^2 of catchment area in highland are certainly of lower capacity than that of either Tehama or southern lowland region due to more outcrop rocks and more slopes outwards as central highland region compares to Western and Southern regions. Furthermore, flow volumes of those Southern and Western Slopes are higher than anywhere else in the country. For catchment areas of a few thousand km^2 and larger, annual runoff volumes are less than 10 % of the annual rainfall volumes. Higher runoff coefficients are to be expected for smaller catchments, because these offer statistically fewer opportunities for losses. Runoff coefficients for individual intensive rain storms during wet periods can be much higher than the annual average coefficients, because the physical processes that produce losses -such as evaporation and evapotranspiration are limited in their rates.

The outcome analysis of surface water assessment depends on geographic, topographic and soil cover features. Differences on estimation rely on specified value of coefficient and any slight modification on this value is reflected in a considerable yield of groundwater recharge. It is believed that current estimated value is accurate since it depends on catchments aggregation and segregation of wider extent covering the whole country and then assigned to main regions and sub-basins or valleys.

4.2 Sources of Irrigation

The percentage of irrigated area in Hadramawt governorate has considerably decreased from 90% to 49 % of the total cropped area between 2007 and 2008. Cropped area irrigated from groundwater has decreased from 15,622 hectare to 13,551 representing a decrease of 13 % during the same period. A good indicator has been already presented toward water use for irrigation and groundwater sustainability as irrigated area from groundwater has been shrinking. Irrigated area is accounted for 62% of total irrigated area in 2008. Surface flow is the second source of irrigation representing 20% , the dams as source of irrigation accounted for 12%. In general, all sources of irrigation witnessed a decrease in the size of irrigated area as the fallowing table explains, however, figure of rain-fed area in 2007 is questionable, since the cropped area that depended on rain represent only 10% as Table 2.4 indicates. I believe, rain-fed figure in 2007 could be speculative.

Table 2.4 : Cropped Area by Sources of Irrigation, Hadramawt 2004-2008

Year	Hadramawt Cropped Area (Ha)	Cropped Area by Source of Irrigation (Ha)						Irrigated Area	
		Rains	Wells	Floods	Streams	Dams	Tanks	Area (Ha)	% to Total
2007	46,821	4,570	15,622	14,223	5,312	7,094	0	42,251	90
2008	44,370	22,496	13,551	4,410	879	2,587	422	21,849	49
2008%	100%	51%	62%	20%	4%	12%	2%	100	49%

Resource: Economic Benefit/cost analysis, FAO,2008 (figures of 2004)

MAI, Year Book Statistics, 2009 (MAI, May 2009)

4.3 Groundwater systems

Studies on groundwater in different areas in Yemen are frequently far from uniform as TON report noted. The main aquifer basins and their variations are analyzed and compared on a national scale, then in regional and sub-regional levels with attention to re-interpret the available information with implementation of several but consistent methods for tabular organization and classification.

The UNESCO has classified aquifers into 8 categories, based on characterization of the storage of groundwater and the permeability of the rock being linked to both pores and fissures.

Most of basins and valleys in Hadramawt governorate are of the first and second class type aquifers described above as highly to moderately productive aquifers. There are 11 sub-basins in the alluvial aquifer systems in Hadramawt presented in table 3.5. These valleys and plains constitute sub-aquifers of considerable capacity of water absorption and their productivity is high to moderate. A brief description of the main groundwater recharge systems in the Governorate is as follows:

Generally, the Arabian Sea basin is much drier than the Red Sea Basin and the Gulf of Aden basin. Furthermore, bare rocks are predominant in its runoff producing catchment zones. The most important groundwater basins in Hadramawt Plains are Almukalla, Al-Masilah and Wadi Hadramawt among other valleys scattered in the governorate.

Valleys and plains in the governorate are filled to great depths, more than several hundred meters with alluvial deposits, which constitute the main aquifer system. On other plains -where there is hardly any alluvial material- groundwater is mainly found in the volcanic rocks. These constitute a fissure-type aquifer, which is locally fairly permeable because of tectonic features. It seems that under these Southern Central Highland Plains the volcanic rock complex is more productive than in most other zones where the Yemen Volcanic is present.

A more diverse geology is found in the area of the governorate. The main aquifer consists of fractured sediments and sandstones. The above presented valleys and basin are overlain by Quaternary alluvial deposits. Volcanic rocks occur in nearby areas, but are locally less important groundwater systems. In general, water quality is good to moderate, but groundwater becomes brackish at the down flow end of the coastal plains. Groundwater is over abstracted in most populated area, which has led to locally significant declines of the groundwater levels.

4.4 Groundwater Recharge Estimation

The most important source that induced groundwater recharge in Yemen is quantitatively the infiltration losses produced in irrigated zones. In intensely irrigated zones such as the According to the hydrological study reported in WRAY-35, infiltration from irrigation in Highland Plains may exceed the natural recharge of the groundwater reservoirs. Induced recharge by discharge of domestic or industrial waste waters is comparatively neglected in Yemen, at least from the point of view of water quantity. Artificial recharge is not practiced at all.

However, assessment of net groundwater recharge based on infiltration through natural cycle of surface water as compared to induced infiltration through irrigation.

The main source of aquifer recharge of Hadramawt plains is by infiltration of runoff surface water from upper rainfall catchments drain into valleys' beds. Direct recharge from rainfall falling on to the catchment area is generally unimportant in the western and southern lowland areas due to relatively low annual average of rainfall combined with more rain required for the soil column moisture in dry areas. Only when rainfall with high intensity occurs during few days, it is possible for the soil profile to be fully saturated. soil profile produces considerable recharge to the groundwater basin below.

Various methods of recharge estimation have been reported in the literature. The choice of a particular method depends on the type of data available.

The total recharge of the governorate basins is estimated in 2008 at 151 MCM / year as the recharge aggregated for the 11 sub-basins in the governorate. Wadi basins vary in their recharge yields according to the size of their catchment areas and mean annual rainfall as well as the value adopted for coefficient. High contribution of recharge yields are presented by Wadi Hajar, Wadi Amd-Daon, Wadi Idim and Wadi Mayfa'ah which account for about 70% of the total groundwater recharge in the governorate as Table 2.3 and figure 2.11 portray. Fore convenience, Table 2.3 is reproduced below to show recharge volume in relation to runoff in Hadramawt governorate.

Figure 2.11 compares the runoff volumes with recharge rate in 2008 for the relevant Valleys. Their difference in recharge rate is referred to the variation extent and size of the catchment area and rainfall amounts and the controlling factor of spate irrigation on which surface irrigation prevent part of the runoff water volume from filtering down to recharged aquifers.

Table 2.3 Mean Annual Runoff for runoff producing catchments in Hadramawt

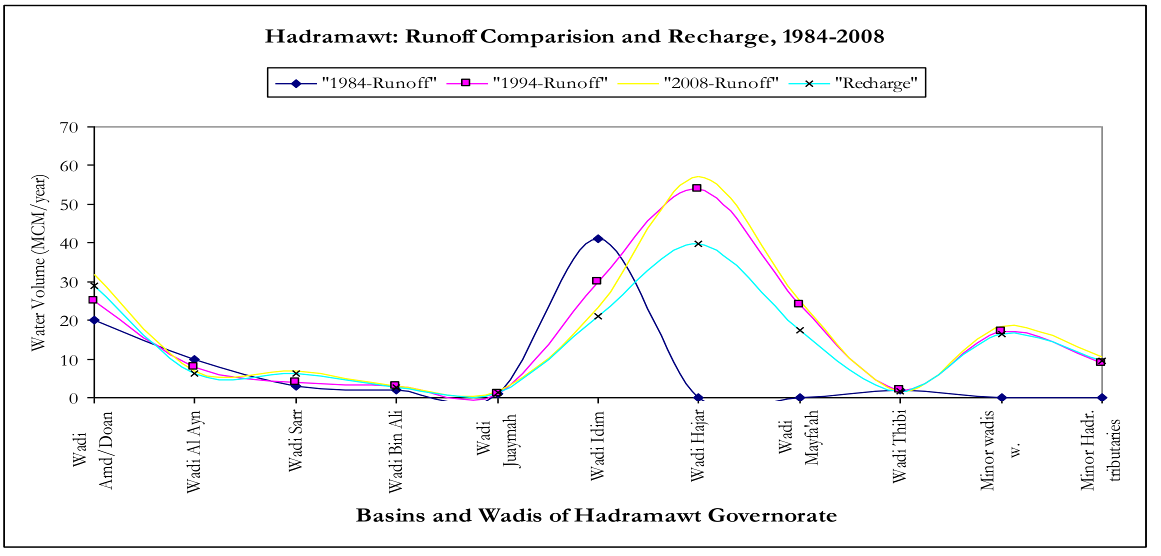
Project 16	Southern Coastal Plains& N. Plains	Catchment	Mean Annual Rainfall		Mean annual runoff				Recharge Volume	
		Area	(82-2008=28yr)		(1980-2008)					
	ARABIAN SEA BASINS	(Km2)	mm/yr	Mm3/yr	2008 mm/yr	2008 Mm3/yr	1984 Mm3/yr	1994 Mm3/yr	2008 mm/yr	2008 Mm3/yr
Coefficient Values					**0.608**	**0.608**	**gauged**	**0.0539**	**0.904**	**0.904**
Hadramawt	Wadi Amd/Doan	6550	80	524	5	32	20	25	4.4	29
	Wadi Al Ayn	1500	75	113	5	7	10	8	4.1	6
	Wadi Sarr	2540	45	114	3	7	3	4	2.5	6
	Wadi Bin Ali	720	65	47	4	3	2	3	3.6	3
	Wadi Juaymah	760	35	27	2	2	1	1	1.9	1
	Wadi Idim	5485	70	364	4	23	41	30	3.8	21
	Wadi Hajar	9900	100	990	6	57	x	54	4.0	40
	Wadi Mayfa'ah	4300	100	430	6	25	x	24	4.0	17
	Wadi Thibi	720	40	29	2	2	2	2	2.2	2
	Minor valleys w.	3000	100	300	6	18	x	17	5.5	16
	Minor Hadr. Tributaries	3800	45	171	3	10	x	9	2.5	9
	Total(155,376)	***39,275***	***69***	***3128***	***4***	***186***	***79***	***177***	***4***	***151***

Note: Mean annual rainfall is referred to the average catchment producing areas while recharge is referred to absorbing areas

Sources: Ministry of Agriculture and Irrigation Compiled from different tables presented in "Water Resources, Report-35, 1996"

The Table is compiled from various sources.

Figure 2.11: Hadramawt Runoff and Recharge Water Volumes 2008



Source: Table 3.5

The line-chart presents recharge volume in relation to runoff volumes in the runoff absorbing valleys. This trend suggests a provision of quick service advisory to help in managing groundwater and water source sustainability. Recharge curve runs closer to those of runoff volumes, since both variables are dependent on and proportionately related to the rainfall amount and catchment sizes. Therefore, the larger the size of a catchment with higher rainfall mean, the higher is the proportion of recharge rate and consequently the more is the groundwater availability.

The correlation coefficient between catchment area and recharge rate across valleys basins is (0.975) higher than the correlation between mean annual rainfall and recharge rate (0.722) suggesting that groundwater volume is more dependent on aquifer size and on physical features than rainfall average. Therefore, maintenance work at local basins such as terracing and artificial structures for water traps lead to more groundwater sustainability.

4.5 Groundwater Balance

Looking at the available information on groundwater levels of the main aquifers in Yemen, including Hadramawt basins, are depleting and increased abstraction have drastically declined groundwater levels to alarming figures. This phenomenon is generally observed in almost all areas.

Estimation of groundwater balance involves determination of several hydrological parameters and many variables involved in each parameter. The most important are those variables related to the mean annual rainfall and runoff volumes, associated with catchment size of producing and absorbing areas that are shown in previous table (2.3). Natural recharge coefficient depends on scaling down the rainfall and runoff in mm or m/ year with catchment size in m^2 to the quantity in m^3, in addition to topographic coverage and soil features in terms of permeability, porosity, transmissivities and level of slopes…etc.

For Hadramawt, the runoff coefficient value is 0.0608 in relation to rainfall while the recharge coefficient is 0.904 in relation to runoff volumes, a value higher than that of the Gulf of Aden Basin or western Red Sea basin recharges due to quality deference in soil permeability, the effect of sloping degree of the surface and the size of catchment. These coefficient values are determined on ground of regional and local parameters of geological as well as hydrological relevant conditions and depend on the past experience and the measurements undertaken by several projects. Further, the third parameter of abstraction and the availability of accumulated groundwater storage of the concerned basins is considered. Data of water storage volume for main regional basins in Yemen on which this analysis partially depends on is obtained from WRAY-35 Report, 1995 taken into account the effect of time on rainfall availability and water consumption.

Table 2.5 demonstrates 11-samples on field units covering an area of 15 hectares and they are taken from deferent districts of Hadramawt governorate. The average per hectare water unit consumed for irrigation using traditional method is 12,439 m^3/ha for various types of crops, however, this average of water use for the same crop pattern reduced by an average of 25 %, down to 9,346 m^3/ha based on improved irrigation water use techniques, namely piped conveyance and localized on farm technologies such as drip, bubbler and sprinkler irrigation. The difference between traditional and modern methods used in irrigation is (3,093 m^3/ha) which is accounted for water saving in the project. Variation of water saving is relevant to cropping type, methods of irrigation and geographical characteristics of the cultivated area. The water saving ratio increases with crops of more water demanding type. For example, higher percentages of water saving (41 %) associates with sour fruit using bubbler method and (37 %) saving with eggplants cultivation using drip system while lower percentage of saving (15-18 %) associated with the use of piped conveyance as less improved irrigation system.

Aggregating and averaging water saving for all samples as measured on the field units and applied to the whole irrigated area in Hadramawt Governorate would result in around 67.7 MCM/year as saved water in the governorate assuming that all irrigated land be covered with modern irrigation techniques. The high value of water saving is proportionally related to the size of irrigated area, method of irrigation and the type of technologies used for irrigation as they are indicated in the samples of Field Units (sample number 10 and 8, in Qasim and Alqatn Districts with sour-fruit and eggplants cultivation) in table 2.5.

Table 2.5: Water Consumption and Saving, Hadramawt Gov., 2008

Hadramawt Governorate/Dist.		**Cropping type**	**Farm sample area**	**Water Consumption by Irrigation Method**			**Average Saved Water (traditional versus modern)**		
Sample No.	**Project Location**			Traditional	Improved	Irrigation	Sample	Govern	percent
			(ha)	(m^3/ha)	(m^3/ha)	method	(m^3/ha)	(Mm^3)	%
1	Alkatn	Alfalfa	2	24,827	20,885	pipe conv.	3942	14.85	16
2	Shibam	Onion-Sum	1	14,054	12,002	pipe conv.	2052	1.44	15
3	Shibam	Onion-Win	1	8,370	7,121	pipe conv.	1249	0.87	15
4	Howrah	Potato	2	6,360	5,431	pipe conv.	929	0.20	15
5	Alkatn	Wheat	1	5,807	4,741	pipe conv.	1066	5.54	18
6	Howrah	Sorghum	2	9,457	7,881	pipe conv.	1576	9.56	17
7	Alkatn	Sesame	2	5,835	4,989	pipe conv.	846	0.68	14
8	Alkatn	Eggplants	1	7,095	4,440	drip	2655	0.30	37
9	Huridah	Tomato	1	6,718	4,800	drip	1918	0.54	29
10	Qasim	Sure-Fruit	1	26,170	15,545	bubbler	10625	8.19	41
11	Howrah	Dates	1	22,137	14,969	bubbler	7168	110.62	32
Total			**15**	**136,830**	**102,804**		**34,026**	67.66	25
Average			**1.36**	**12,439**	**9,346**		**3,093**	**13.89**	25

Source: Ministry of Agriculture and Irrigation, Groundwater and Soil Conservation Projects, compiled from "Farmer Guideline-Hadramawt-, January,2008"

Ministry of Agriculture and Irrigation, Agricultural Statistics Year Book,Mar.,2009"

Area irrigated from groundwater in the consumes 169 MCM /year of groundwater, corresponds to total abstraction of water used for irrigation. It is a huge volume of water use, particularly with respect to 25 % saving average in water. Around 42 MCM/year of water in all irrigated area could be saved and contribute to the augmentation of groundwater recharge (169 MCM/year traditional use vs. 127 MCM/year improved systems) as table (2.7) explains.

Looking into the estimation of groundwater abstraction from another point of view on account of the capacity of pumping wells discharge from groundwater, quantity of water abstraction as compared to water crop requirement measured on the field units would be 132 MCM/ year for wells capacity versus 169 MCM/year as compared to the result of hydrological analysis. Estimation of groundwater used for irrigation varies according to each method. The difference between the two methods of estimation, namely water crop requirement and pumped wells capacity is believed to be a function of input parameter in relation to pumped water since not all irrigated crops were considered throughout the year in terms of pumping hours per water unit for all irrigated area. Hence, variation of water estimation is expected based on different methods with deferent inputs parameters. For example, groundwater irrigation is made more than one season a year, and due to incomplete data input of exact average in pumping hours during the year, the result figures are not coincided. Therefore, in each case, the results of our analysis are relevant as they based on seasonal water irrigation as measured on the field. Furthermore, the average pumping capacity is estimated in relation to pumping hours multiplied by the total number of wells and by the area based irrigated crop requirements. Finally, the current hydrological analysis has been approved to be accurate according to different methods used to check validity.

Table 2.6: Groundwater Consumption and Saving, Hadramawt Gov., 2008

Hadramawt Governorate/Dist.		**Hadramawt Cropping Pattern**	**Total Irrigated Areas**	**Average wells discharge per crop(47-80 m3/hr)**		**Water Consumption and Saving by Irrigation Method**			**Irrigated Area from Groundwater:2008**	
Sample No.	**Project Location**					Traditional	Modern	Saved	Crop. Area	Water vol
			(ha)	(Mm^3)	(hrs/ha)	(Mm^3)	(Mm^3)	(Mm^3)	(ha)	(Mm^3)
1	Alkatn	Alfalfa	3,768	44.57	408	93.55	78.69	14.85	2,334	58
2	Shibam	Onion-Sum	701	4.92	242	9.85	8.41	1.44	434	6
3	Shibam	Onion-Win	700	2.94	145	5.86	4.98	0.87	434	4
4	Howrah	Potato	215	0.88	141	1.37	1.17	0.20	133	1

Hadramawt Governorate/Dist.		Hadramawt Cropping Pattern	Total Irrigated Areas	Average wells discharge per crop(47-80 m3/hr)		Water Consumption and Saving by Irrigation Method			Irrigated Area from Groundwater:2008	
Sample No.	Project Location					Traditional	Modern	Saved	Crop. Area	Water vol
			(ha)	(Mm^3)	(hrs/ha)	(Mm^3)	(Mm^3)	(Mm^3)	(ha)	(Mm^3)
5	Alkatn	Wheat	5,196	21.24	141	30.17	24.63	5.54	3,219	19
6	Howrah	Sorghum	6,069	25.51	145	57.39	47.83	9.56	3,760	36
7	Alkatn	Sesame	809	2.04	87	4.72	4.04	0.68	501	3
8	Alkatn	Eggplant	114	0.24	74	0.81	0.51	0.30	71	1
9	Huridah	Tomato	280	0.90	111	1.88	1.34	0.54	173	1
10	Qasim	Soure-Frut	771	5.68	254	20.18	11.99	8.19	478	12
11	Howrah	Dates	3,251	23.00	244	71.97	48.66	23.30	2,014	45
Total		**Total**	**21,874**	**132**	**1992**	**272.09**	**204.43**	**67.66**	**13,551**	**169**
Average		**Average**	**1,989**	**12**	**181**	**24.74**	**18.58**	**6.15**	**1,232**	**17**

Source: Ministry of Agriculture and Irrigation, Groundwater and Soil Conservation Projects, compiled from "Farmer Guideline-Hadramawt, January,2008"

Ministry of Agriculture and Irrigation, Agricultural Year Book Statistics,Mar.,2009"

5. ESTIMATION OF WATER SAING IN HADRAMAWT

With respect to Hadramawt MIP, the amount of groundwater could be saved as a result of the implementation of concerned project (12,800 ha) is estimated to be about 39.6 MCM/year or 25% of current water use as a function of multiplying the average water saving (3,093 m^3 /ha) in the sample on the field units in the governorate with the targeted project area that is 19, 400 ha. as is shown in table 2.7 Another countable benefits is from cut-back spending on pumping hours, cost of water and energy, labor wages and so on., in addition to invisible aspects of economic benefits such as stability and a sustainability of groundwater use for the locals as well as for the nation.

The project components comprise piped conveyance systems for 8,000 ha of irrigated areas and localized on-farm irrigation system for 4,800 ha of which 3,000 ha fruits under bubbler system and 1,800 ha vegetables under drip system, in addition to irrigation Advisory services and technical supervisory/advisory support. Table 2.7 shows the project components along with average water use and saving for each sub project acreage and system.

Table 2.7: Water Use and Saving Indicators Hadramawt Project

Hadramawt: Average Water use and Saving 2008	Conveyance Pipe System			Modern On-Farm Irrigation System			Total
	Total	Cereals	Cash Crop	Total	Vegetables	Fruits	Area
	Ha	Ha	Ha	Ha	Ha	Ha	Ha
Targeted area(ha)	8,000	4,000	4,000	4,800	1,800	3,000	12,800
Traditional (MCM/yr)	99.5	49.8	49.8	59.7	22.4	37.3	159.2
Improved (MCM/yr)	74.8	37.4	37.4	44.9	16.8	28.0	119.6
W. Saving (MCM/yr)	24.7	12.4	12.4	14.8	5.6	9.3	39.6
Average W. Saving (%)	24.9	24.9	24.9	24.9	24.9	24.9	24.9

Source: Ministry of Agriculture and Irrigation, Groundwater and Soil Conservation Projects, compiled from "Farmer Guideline-Hadramawt-Taiz, January,2008"

MAI, IIP, Economic Benefit-Cost analysis, FAO, 2008

Ministry of Agriculture and Irrigation, Agricultural Statistics Year Book, Mar.,2009"

Comparison between outcomes of the two studies in terms of water saving for Hadramawt in quantities and percentage are 1,982 according to economic analysis versus. 3,093 m^3 /ha based on hydro-analysis, corresponds to 26% vs. 25% respectively as shown in the tables above. Almost identical results of saving in percentage by the two studies, but variation in the absolute number between FAO and current project estimate is attributed to the parameter extent/size on which the two studies depend and from which they were drown their sample data of water saving estimates. For example, economic analysis relied on 6 cropping samples while hydrological study relied on 11 cropping samples from different districts in Hadramawt governorate. Therefore, the later estimate is probably more reliable. Even though both studies investigate the same project and for the same area and relied on the same data source, obtained from demonstration field units as reported by GWSCP.

A very small difference of the average water saving would result in a great amount as it is to be generalized to the whole irrigated area in the governorate, and/ or to basin discharge or to a regional aquifers, hence a careful estimate of water saving in relation to recharge-discharge parameter and further check out should be taken in such estimates. (Irrigation M. o., Groundwater and Soil Conservation Project (GWSCP), 2007-2008)

5.1 Critical Basins and Groundwater Abstraction

One of the main aims of the MIP is to reduce groundwater abstraction and recover groundwater levels. Unless groundwater recharge is reasonably estimated this cannot be achieved. Water abstraction, recharge estimates and water balance for various groundwater districts in Hadramawt are analyzed and the results are shown in Table (2.11) below. However, these estimates can be considered as approximate and hence there is a rational ground to make reliable estimate. Hadramawt basins are divided into districts based on factual data obtained from Agriculture Census for wells inventory and from Year Book Statistics and other sources that are combined with previous tables to produce table 2.11.

Table 2.11: Groundwater Abstraction, Recharge and Water Balance, Hadramawt 2008

Series	Hadramawt Districts	Total Agricultural Area (ha)	No. of wells	Water abstraction *(wells discharge)*		Groundwater irrigated crops		Water Recharge		Water Balance *(Discharge-Recharge)*		
				Mm^3/yr	%	(ha)	%	m^3/yr	%	Balance Mm^3/yr	% Balance	R/D
Total Governorate		54,422	7865	169	100	13,551	100	151	100	-18	0	1.1
1	Ramah	26	0	0.00	0.00	-	0.0	0.07	0.05	0		0.0
2	Thamoud	45	8	0.17	0.10	14	0.1	0.13	0.08	0	0	1.4
3	Qaf-Ala'awamer	469	6	0.13	0.08	10	0.1	1.30	0.86	1	9	0.1
4	Zamakh Wamanokh	1329	0	0.00	0.00	-	0.0	3.69	2.44	4		0.0
5	Higer-Alsaia'ar	2137	0	0.00	0.00	-	0.0	5.93	3.93	6		0.0
6	Ala'abr	828	4	0.09	0.05	7	0.1	2.30	1.52	2	26	0.0
7	Alqatn	11349	993	21.28	12.63	1,711	12.6	31.49	20.85	10	0	0.7
8	Shibam	3817	868	18.60	11.04	1,496	11.0	10.59	7.01	-8	0	1.8
9	Sah	743	124	2.66	1.58	214	1.6	2.06	1.36	-1	0	1.3
10	Saya'own	3302	701	15.02	8.91	1,208	8.9	9.16	6.07	-6	0	1.6
11	Trim	3904	360	7.72	4.58	620	4.6	10.83	7.17	3	0	0.7
12	Assawm	1255	410	8.79	5.21	706	5.2	3.48	2.31	-5	-1	2.5
13	Arraidah	1226	201	4.31	2.56	346	2.6	3.40	2.25	-1	0	1.3
14	Addais	408	50	1.07	0.64	86	0.6	1.13	0.75	0	0	0.9
15	Ashaher	898	1137	24.37	14.46	1,959	14.5	2.49	1.65	-22	-1	9.8
16	Ghail-BenYamin	898	384	8.23	4.88	662	4.9	2.49	1.65	-6	-1	3.3
17	Ghail-BaWazir	1403	569	12.19	7.23	980	7.2	3.89	2.58	-8	-1	3.1
18	Almukalla	737	541	11.59	6.88	932	6.9	2.04	1.35	-10	-1	5.7
19	Dawa'n	343	13	0.28	0.17	22	0.2	0.95	0.63	1	2	0.3
20	Wadi-Ala'in	3579	226	4.84	2.87	389	2.9	9.93	6.58	5	1	0.5
21	Rukhaiah	1034	0	0.00	0.00	-	0.0	2.87	1.90	3	0	0.0
22	A'amedd	1907	0	0.00	0.00	-	0.0	5.29	3.50	5	0	0.0

Series	Hadramawt Districts	Total Agricultural Area (ha)	No. of wells	Water abstraction *(wells discharge)*		Groundwater irrigated crops		Water Recharge		Water Balance *(Discharge-Recharge)*		
				Mm^3/yr	%	(ha)	%	m^3/yr	%	Balance Mm^3/yr	% Balance	R/D
23	Addulaiah	1456	0	0	0.00	-	0.0	4.04	2.67	4	0	0.0
24	Yaba'ath	92	0	0	0.00	-	0.0	0.25	0.17	0	0	0.0
25	Hagr	1856	165	3.5	2.10	284	2.1	5.15	3.41	2	0	0.7
26	Brome	3030	443	9.5	5.63	763	5.6	8.41	5.57	-1	0	1.1
27	Hdibaw	174	481	10.3	6.12	829	6.1	0.48	0.32	-10	-1	21.3
28	Qalansiah	42	142	3.0	1.81	245	1.8	0.12	0.08	-3	-1	26.0
29	Huraidah	6137	40	0.9	0.51	69	0.5	17.03	11.28	16	19	0.1

Note: Estimate of Pumped Wells Discharge =(av. amount of pumped water/hr *no. hours*no. wells)

Variation is attributed to the number of wells while pumping capacity of wells is constant and irrigated cropping area is proportionate to no. of wells

Source: Ministry of Agriculture and Irrigation, Groundwater and Soil Conservation Projects, compiled from "Farmer Guideline- Hadramawt, January,2008"

Ministry of Agriculture and Irrigation, Agricultural Statistics Year Book, Mar.,2009

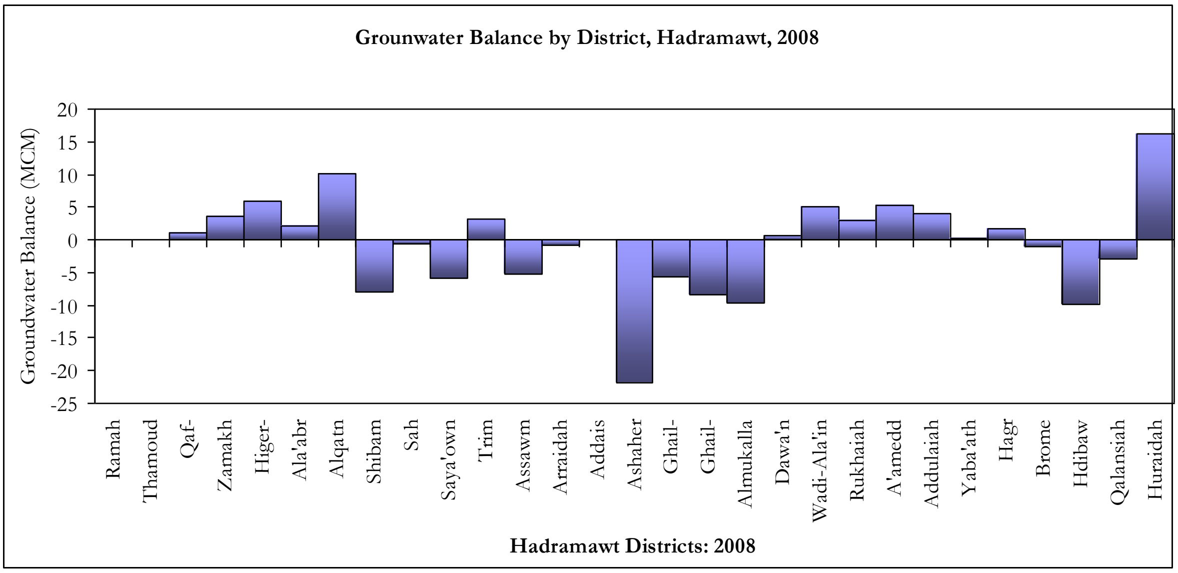
Ministry of Agriculture and Irrigation, 2002 Agricultural Census, Augest,2004.

Based on Agricultural Census of 2002, there were about 7,865 pumped wells in Hadramawt governorate. According to hydrological analysis, the pumping capacity of these wells is estimated at 169 MCM for the 2008 as noted earlier. Surface wells with no pumping equipment are excluded from this analysis since large amount of water abstraction is associated with mechanical pumps installed in the wells. Despite this exclusion, the number of wells is still too large, by definition for poor aquifers recharge and storage.

The growing groundwater deficit is proportionally associated with the number of wells presented in a district. For example, threatening situation of groundwater is presented in a number of districts: Ashahir, Al-Mukalla, Hadibaw, Ghil-ba-Wazir, and Shibam districts where the annual water deficit negatively ranges from 8 to 22 MCM /year. The total water deficit in the governorate is -18 MCM in 2008. Abstraction ratio (recharge/abstraction) represents nearly 1.1 times of recharge rate in well equipped pumping wells districts, even though some districts are still worse making an imbalanced groundwater situation where abstraction is up to 22 -26 times of recharge rate such as in Hdibaw and Qalansiah Districts.

The overall excessive groundwater abstraction in the governorate is 18 MCM/year or 10 % misbalanced with recharge rate as table 2.11 and figure 2.12-2.13 indicate.

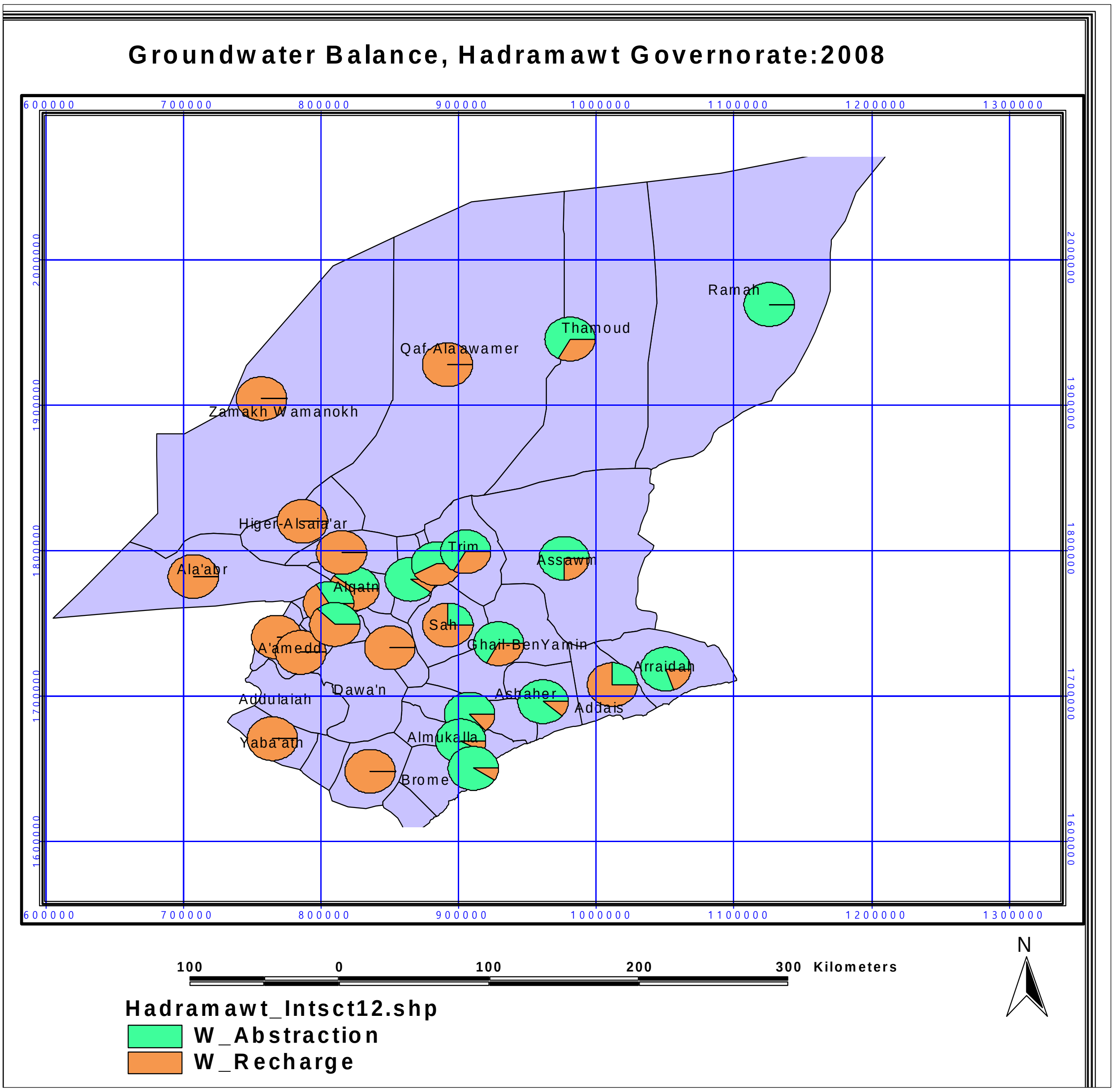
Figure 2.12: Groundwater Balance Distribution by Districts, Hadramawt 2008



Source: Table 2.11

Figure 2.13 explores the spatial distribution of aquifer water balance in Hadramawt as groundwater abstraction is compared to recharge. From bar chart, It is easy to recognize the excessive abstraction over the recharge rate of the local aquifers. (Irrigation M. o., Groundwater and Soil Conservation Projects, compiled from "Farmer Guideline- Hadramawt, January,2008) (Irrigation M. a., Augest,2004) (Irrigation), 2009)

Figure 2.13: Spatial Distribution of Water Abstraction vs. Recharge by Districts of Hadramawt, 2008



5.2 Water Levels

Nearly all groundwater basins in Yemen experience a serious dropdown water level. For example, one of recent study *"Water Conservation and sensible use of Water, 2008)* indicates that some wells shows that water levels have continually dropped down since they being constructed during the last decade. The average depth is more than 150 m from the ground surface. Another indicator of water level depletion is that considerable number of wells has been deepened down to some 165 m from less than 100 m during the last decade, which means a drop in water table more than 6 m a year.

6. Hydrological Evaluation and Monitoring:

Hydrological study analysis has shown the advantage and gained benefits of MIP implementation, particularly, a significant amount of water 39.6 MCM/year would be saved in the governorate as result of installing and adopting the Modern Irrigation Technologies through 12,800 ha. using improved irrigation in the current project. This figure is based on analyses of valid data collected from field units' water measurement. The project also preserves the nation's water recourses and make them sustainable apart from the gains comes from the cutoff cost of water, energy consumed, and from the decrease in labor work in form of wages. Furthermore, invisible benefits are associated with community such as regulation, awareness, and technical experience at various levels.

Data samples parameters of on-farm Field Units and on pumping capacity of wells by GWSCP has all been taken variably in order to accurately assess groundwater discharge in relation to groundwater recharge, in addition to further check out validity of recharge estimation. Variables of these parameters are all used in association and compared with groundwater abstraction and recharge rates and further subdivided from governorate to district level in purpose to define and establish control systems of water consumption in both ground and surface or spate irrigation for each district.

7. Research Conclusion:

There is a current and evolving deficit between the availability of groundwater resources and their use in many districts in Hadramawt, particularly in Ashahir, Al-Mukalla, Hadibaw, Ghil-ba-Wazir, and Shibam districts. Around one-third of the districts (10 districts) experiencing an excessive groundwater abstraction over recharge rate in the governorate. Some districts show a considerable deficit while other show more recharge gain over abstraction and of some districts show the balanced situation between groundwater abstraction and recharge rate.

Based on the results of data analysis, it is found that many groundwater basins are experiencing a water deficit where recharge rate is too far less from balancing situation to compensate for growing groundwater abstraction. It is anticipated that groundwater abstraction increase steadily over time due to the rapid increase in population growth as well as the increasing area of irrigated crops unless mediation is to be taken by concerned authorities and communities to regulate and manage in sustainable manner the groundwater resource in Yemen. Controlling indicators are set forth to help managing and sustain groundwater and agriculture development.

The project aims to improve water management and increase irrigation efficiencies in project area. The project will contribute to mitigating the rapidly emerging freshwater shortage that could impede progress and economic development in the country. The project would aim at expanding irrigation improvement and modernization at the farm level and implement participatory groundwater management and conservation advisory services.

Looking into the estimation of groundwater abstraction from another point of view on account for the capacity of pumping wells discharge from groundwater, quantity of water abstraction as compared to water crop requirement measured on the field units would be 132 MCM/ year for wells capacity versus 169 MCM/year as compared to the result of hydrological analysis.

The current hydrological analysis has been approved to be accurate according to different methods used to check in validity. Around 42 MCM/year of water in all irrigated area could be saved and contribute to the augmentation of groundwater recharge *(169 MCM/yr traditional use vs. 127 MCM/year improved systems)*

Based on the results hydrological analysis and all facts associated and disused throughout this study to achieve the main objectives for groundwater assessment in Hadramawt Governorate, the research findings suggest the Ministry of Agriculture and Irrigation in Yemen with help of its regional officers and farmer organizations should complete installation of all system's components of the Modern Irrigation in the target sites and further undertake a comprehensive survey related to underground water irrigation and to seek other ways in order to maintain groundwater resources.

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Annex-B: Arabic References

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