Yemen's Water Sector Reform Program
A Poverty and Social Impact Analysis (PSIA)
Christopher Ward, Sabine Beddies, Khaled Hariri, Souad Othman Yaffiei
Anwer Sahooly and Barbara Gerhager
and Ministry of Water and Environment
Ministry of Agriculture and Irrigation
2007

Finally, there can be a problem of equity within WUAs: the basis of a WUA is a 'democratic' one, but experience is that large farmers and water resource owners will not join – this was the problem that undermined the WUAs set up in the mid-1990s in Habir and al Haima near to Ta'iz under the Ta'iz Pilot Water Supply Project. The sheikhs who controlled most of the wells were simply not interested in joining. And when larger farmers do join in, as in Wadi Tuban and Wadi Zabid under IIP, the problem is then how to avoid their controlling decision taking.

Yemen
Assessing the Impacts of Climate Change and
Variability on the Water and Agricultural Sectors
and the Policy Implications
Sustainable Development Sector Department
Middle East and North Africa Region
April 2010

Yemen five eco-climatic zones

A hot and humid coastal Tehama plain, 30-60 km wide, along the Red Sea and the Gulf of Aden

Changing water balance and frequency of spates for Wadi Surdud

Tehama, an important agricultural area that relies on a combination of spate irrigation and groundwater abstraction from a coastal aquifer. Rainfall along the Red Sea coast is very low. Agricultural production increased following the development of modernized spate irrigation schemes based on permanent diversion structures in the 1980s.

Total groundwater abstraction in the lower catchment in the mid 1990s was much greater than the natural recharge, which derived from inflows from the upper catchment together with small amounts of local recharge. Application of the climate change scenarios for the 2030s, 2050s and 2080s to the daily hydrological models showed:

A range of potential flow changes from a decrease of about 20% to an increase of about 30% for the dry and wet scenarios, respectively.

No significant change in the average frequency of spate flows (see foot note 19 below), with more or less flow during spates in accordance with the application of wetter or drier scenarios.

A large difference in the frequency of spates for individual downscaled scenarios demonstrating that this important variable would change with different patterns of daily rainfall.

Continued over-abstraction of the coastal aquifer even in the wettest scenarios, making it clear that water efficiency and improved water resources management at the catchment scale are needed irrespective of any future climate scenario.

Further development of spate irrigation should ensure an efficient and equitable balance between water uses and users. Investment in spate irrigation is a high priority

measure, particularly for the Tehama and the south coast. Planning at the basin scale is required to ensure that the water resource is managed optimally. This should include technical and economic optimization to ensure the correct balance between use in the highlands, recharge of the coastal aquifers, diversion for spate irrigation, and environmental flows, particularly to manage saline intrusion, an increasing threat under climate change.
Water resources planning should also take account of equity aspects, ensuring that water resources are shared equitably, and that new arrangements do not cause uncompensated losses to existing users, which has been a problem with past spate improvement.24

Yemen's four main surface water basins
The Red Sea Basin: A number of large wadis drain the steep western escarpment and lose most of their water in the permeable sediments of the coastal Tehama.

Vrank van steenbergen and nawalel haouari
The blind spot in water governance: Conjanctive groundwater usein the MENA countries
Main Water Management Issues
identified in Wadi Tuban and Wadi Zabid in Farmer Focus Groups
Decreasing inflow into the system – probably related to the increase of dams upstream;
Sedimentation of the spate system resulting in land going out of control, sand deposition in fields and heavy sedimentation in canals;
Increasing inequity in water distribution – related to the increase in banana and mango cultivation; Decreasing groundwater table.

Water in the
Arab World:
MANAGEMENT PERSPECTIVES
AND INNOVATIONS
N. Vijay Jagannathan
Ahmed Shawky Mohamed
Alexander Kremer
MIDDLE EAST AND NORTH AFRICA REGION
THE WORLD BANK
2009
Wadi Zabid Downstream Farmers Conflict with Upstreamers
Water in Wadi Zabid's spate system is managed according to rules devised over six centuries ago by the Moslem scholar, Sheikh Gebrati. The rules are based on "upstream first": *al 'ala fa al 'ala.* The rules divide the waters among three "regions." In the dry season, there are base flows only. They go to the upper region. In the rainy season, when the floods come, the spate is divided among:
- Upper region: First 97 days
- Middle region: Next 20 days
- Lower region: Last 35 days.

The channel master allocates water to plots and decides which plot will get irrigated first by the next flow. The rule is: "Not twice in 14 days." The channel master collects

charges proportional to the irrigated area. The rate is lower in the middle area, and negligible in the lower area.
Prior to 1973, many conflicts over water distribution were recorded. The conflicts claimed several lives each year. When a World-Bank-financed project modernized the system in 1973, the situation became better for all. Water control improved, and the state enforced water discipline.
After 1985, matters deteriorated. The fruit import ban changed incentives, and the upstream farmers planted bananas, which needed irrigation every five days. There was also some expansion of the irrigated area upstream. Even some lands in the upper region no longer got base flow due to the demands of the bananas and to illegal diversions by big landowners. "Daily conflicts over water" were reported. Small farmers lower down were forced to sell and to become sharecroppers.
Source: Al-Eryani and others 1998.

Formulation of Water User Organizations toward Cost-Sharing

The IIP was articulated around Participatory Irrigation Management (PIM). The project prompted the government to create enabling legal and institutional environments to establish two main irrigation-user organizations: water user associations (WUAs) and irrigation councils (ICs). Each WUA is in charge of implementing PIM in its respective irrigation command area.
The WUA was to (1) provide reliable and sustainable irrigation services, (2) perform maintenance and rehabilitation, (3) collect fees from beneficiaries, and (4) develop the capability for self-reliant O&M.
At later, more advanced stages, ICs were established in both Wadi Zabid and Wadi Tuban with potent representation from the WUAs. The ICs act as the High Executive and Administrative Authorities in each wadi (riverbed). The ICs are responsible for (1) applying the IC's by-laws and implementing its executive procedures; (2) coordinating activities between government authorities that continue to be in charge of O&M of head works/primary canals and the WUAs in charge of O&M of the secondary and tertiary systems; (3) protecting water user rights and resolving conflicts and pending issues; and (4) monitoring the social, financial, and technical performance of WUAs.
The ICs represent the local government, WUAs, and the Ministry of Agriculture and Irrigation (through its Regional Development Authority/ Agriculture Office).
The project initiated the PIM approach through undertaking a comprehensive awareness program to inculcate the concept of PIM in farmers' minds and to clarify the roles and responsibilities of irrigation beneficiaries within their representative user groups. The program targeted all relevant stakeholders, including farmers (owners, sharecroppers, and tenants), government officials, and local councils. As a result of the program, informal water user groups (WUGs) were formulated at the onset, which later metamorphosed into formal WUAs.
ICs were formed at an advanced stage of IIP. The project then developed training activities to build the managerial and technical capabilities of the WUAs and ICs.
PIM called for farmers' participation in overall project activities starting from decisionmaking to completion of the rehabilitation and improvement works, as well as farmers' contribution of 10 percent of investment costs in kind. Thereafter, farmers would take over responsibility and financing for the O&M of secondary and tertiary canals.

IIP's Approach to Community Cost-Sharing of Off-Farm Investments

For the investment/rehabilitation works, as mentioned earlier, the IIP introduced an in-kind cost-sharing approach through community implemented contracts. To enable low-income farmers to share the capital costs of the project, IIP divided civil works into two categories:

1. *Priority works* to be fully financed by the project (government funds and loans). These works include feeder roads and flood/environmental protection works, which are deemed public goods outside the canal system and thus require no earmarked user fees.
2. *Participatory works,* requiring a 10 percent farmer contribution to rehabilitation/improvement capital costs. This percentage was agreed between the project government team and farmer representatives (initially the WUGs; eventually the WUAs). Farmers were allowed to contribute this percentage in kind: labor and material. In this arrangement, each WUA would implement 1–2 small community contract(s) up to $10,000 per contract, to an aggregate $1.4 million per project. To further persuade irrigation end beneficiaries to contribute 10 percent in kind, the project guaranteed.

Social and economic dimensions of non-renewable resources

Mohammed Al-Eryani, Bo Appelgren and Stephen Foster

Concept of socio-economic sustainability

Non-Renwable Groundwater Resources
A guidebook on socially – sustainable management for water policy makers
UNESCO, 2006

'*Into the well from which you drink do not throw stones*'
Arabic Proverb
(literally)

Turton and Ohlsson (1999) have defined the related concept of 'social adaptive capacity to water scarcity'. Social sustainability contemplates consideration of society needs and goals, which will vary with time, place and people.

a **socially-sustainable plan** for use of a non-renewable resource would thus need to be formulated to meet three main conditions (Borrini-Feyerabend, 1997):

- maintaining (or improving) **well being** of communities involved, by meeting as far as possible their social, economic, cultural and environmental needs, now and in the future,
- managing the actions of **concerned individuals or communities** that affect resource use, by strengthening their capacity to cooperate in the management of the resource and assuring appropriate financial, legal, technical, institutional and political conditions for them to adhere to the established management plan,
- address the fundamental concern about human survival not only for present and future generations, by maintaining **inter-generational equity** in terms of benefits derived from the resource and ensure economic and social opportunities to all stakeholder groups including future generations.

Socially-sustainable use of non-renewable resources

It is interpreted here in the **'social context'** – and thus sustainability is not meant to imply 'preserving' the groundwater resource for generations to come, but instead

reconciling the use of the non-renewable resource with the *'sustainability of human life'*.
For groundwater resource management, the typical situation is that :
● diagnostic data are limited,
● use patterns involve a substantial number of individual abstractors,
● impacts are not very visible and often delayed,
● damage to the resource base can have far-reaching and long-term consequences.

SOCIAL AND ECONOM IC DIMENSIONS OF NON-RENEWABLE RESOURCES

In summary the key principles that should adopted for the development of non-renewable groundwater resources (Louvet and Margat, 1999) are :
● the evaluation phase should result in estimates of the volume of groundwater that can be produced in a fixed time-horizon with reference to an acceptable groundwater level decline,
● the development of non-renewable resources must be justified by socio-economic circumstances in the absence of other water resources, and that its implementation is planned and controlled.

Planning for socio-economic sustainability

The planning process for socially-sustainable mining of groundwater resources, or putting the existing mining of groundwater resources on a socially-sustainable basis, must incorporate the following key elements :
● evaluation of 'social well-being' on a periodic basis
● effectiveness of community participation in groundwater regulation
● appraisal of the extent to which 'inter-generational equity' is being met.
Specific criteria or parameters for these elements should be incorporated into the management model developed for the aquifer under consideration.

Criteria for ensuring social well-being in the management of non-renewable groundwater utilisation

CRITERION CONSIDERATIONS
Security of access to water-supply
Based on water-use rights, regulated access and adequate monitoring over the years of the plan, taking into consideration pre-existing groundwater users – relevant instruments include : permit system for water well drilling and groundwater abstraction, scientifically-based spacing requirements between water wells, monitoring of groundwater use/levels/quality, aquifer numerical modeling and periodic drawdown prediction, adjustment of authorised abstractions taking aquifer behaviour into account.
Economic and social opportunity
Planning use of groundwater resources to enhance long-term economic and social development, so as to provide opportunities to all stakeholder groups including future generations.
Just and effective decision-making
Upholding and promoting the right of communities to participate meaningfully in groundwater use decisions affecting livelihoods - including just mechanisms for participation in decision-making during planning and implementation, and resolution of conflicts, distribution of benefits/responsibilities/incentives and compensation for damages resulting from groundwater mining.

Social heritage and identity

Protection of cultural values and life-styles, but this needs to be reconciled with the need to promote economic transformation as regards reduced dependency on scarce water resources through the promotion of high added-value activities.

Environmental considerations

Inventory of ecological services provided by aquifer system concerned, with provision for protection of critical elements, safeguards against the potentially adverse effects of land subsidence and wastewater disposal.

Criteria for promoting community participation in the management of non-renewable groundwater utilization

Proactive government role

Absolutely essential and must ensure appropriate cross-sector consultation for plan elaboration, implementation, evaluation and revision; needs to facilitate equitable 'grass-root' stakeholder participation within an integrated policy framework that treats water as a socio-economic good.

Organisational structure

Partnership between government and stakeholder/social/non-governmental organisations in overall aquifer management organisations for policy development, mobilization of investment and other decision-making; provision of opportunity for social organisation into smaller 'nested' groups for regular communication.

Financing management

Levying some kind of 'water resource abstraction fee' will provide an important signal to users and help generate the financial resources needed for effective user participation in groundwater resource administration, and demand and supply side management.

Capacity building

Necessary to ensure that the communities involved have access to appropriate education, technology and information for implementation – and the plan itself must address the inputs required and provide insight on ways to secure them.

Accessibility of groundwater resource data

To ensure transparency the aquifer management boundaries (both spatial and vertical) need to be well defined, and information on all relevant technical parameters (which determine aquifer storage, yield and quality risks) must be accessible in a 'friendly format'.

Demand management and water conservation

Awareness campaigns and incentives to promote improved water-use efficiency, treatment and recycling of wastewater, and constrain overall demand especially in relation to crop cultivation; promotion of a 'water rights market' could be considered as one possible instrument in this regard.

Inter-generational equity

The inter-generational distribution of benefits focuses on the improvement of social equity over time. It should be a core requirement for successful planning of the mining of non-renewable groundwater resources, and has the following indicators:

- **Improvements in well-being** : the improvement of people's well-being is a good indicator of inter-generational social equity, and hence of the sustainability of the socio-economic development arising from groundwater resource mining, and the plan must define the related parameters and appropriate points for measurement.

● **Enhancement of 'social capital' :** the evolution of capacity of stakeholders to cooperate effectively on resource utilisation is another important indirect indicator of the potential for inter-generational distribution of benefits.

● **Opportunities to younger generations** : an additional factor that needs to be taken into account is the likelihood of younger generations having opportunities created by technology breakthroughs that positively impact on the availability of alternative water supplies – amongst these developments advances in desalination technology (reducing desalinated water cost and environment impact) is likely to be the most significant for the more arid regions.

Tehama Water Resources Management
Wadi Zabid and Wadi Rema'a Water Quality
National Water Resources Authority
2009

According to the last well inventory for the district which achieved by NWRA in 2006, there were about 7572 operational water points in the district , the total abstraction from these wells are 706,640,496 m3.

Geographically Zabid water resources management district is represented in six map sheets scale 1: 50,000 (1443 D1, 1443 C2, 1443C1, 1343 D3, 1443 C4 and 1443 C3).

Zabid water resources management district lies between latitude (UTM=346,000m , 288.000m E) and longitude (1,600,400m , 1,548,000m N). The total area of the project (Wadi Zabid and Wadi Rema'a coastal plain) is about 2242 km2 or 224,200 hectare (DHV,TBWRS, 1988), The average length of Zabid district from the North to South is about 50 km, while the average width is about 45 km.

central statistical organization (CSO), the total population of the project area reaches 412,248 persons. The population in urban communities (province centers and secondary towns) is about 103062 persons (25%) while the population in rural communities is about 309186 persons (75%) and all the population is concentrated in an area of 184 km2.

About 57,000 ha of irrigated area depend on groundwater and 15000 he by spate-irrigation while 552000 he are rainfed.

The average net incomes from irrigated area are about 250000 YR / hectare.

The secondary activity is livestock production especially in the middle area.

The approximate total number of livestock is about 500,000 (2008).

Livestock is a relatively important source of cash income for farmers especially for those situated down streams of Wadis.

Farmers in the deep groundwater irrigated areas depend on the livestock incomes to buy, fuel for their pumping equipment, while the farmers in the rain fed areas largely mainly depend on the livestock incomes due to the low incomes from the cultivated crops.

Farmers in downstream

Groundwater irrigated areas, rain fed areas and bare rangeland areas. This income is generates from the following sources:-

1. Local off-farm incomes such as off-farm agricultural labor, honey processing, fishing, transportation equipment (trucks, buses, vehicles, motor cycles), small shops and building labors

2. Immigration remittance form of the incomes, generated internationally in Saudia Arabia and locally (nationally) in big cities (Hodeidah, Sana'a) and semi urban towns (Zabid, Hussayniah ...etc)
3. Government jobs (teachers, army & police personnel and other official jobs) and government social welfare

1-4 Catchment's Area

The catchment area of Zabid water resources management district includes two major Wadis : Wadi Zabid and Wadi Rima'a. Administratively the catchment area is situated (partially) in three governorates : Dhamar, Raymah and Ibb Governorates.
The catchment area can be divided into two upper catchment areas:

• The north-eastern upper catchment area extending as far as the surroundings of Dhamar and Raymah Governorates at an altitude of (2400)m. This sub catchment area has a relatively dry climate (annual rainfall is 400 mm). It contributes mainly to the base flow and floods for Wadi Rima’a
• The south-eastern upper catchment extending as far as so-called green Yemen region around the city of Ibb, Gabal Sumarah and Al-Odien province. Agriculture in this catchment is very intensive and the rainfall is sufficient (1000 mm). The rainfall is more evenly distributed over the year than in the more arid parts of Yemen.

Geology and Hydrogeology

The stratigraphy of Zabid water resources management district comprised entirely of sedimentary deposits which are over (200 m) thick (B.L morric). The subsurface geology forms basically a continue which can be divided into two broad faces based on grain size, which decreases west-wards as a factor both of degree combination of sediment transport capacity as the Wadi spate is dissipated on route to the sea. Altogether four main physiographic units can be recognized within the land for the coastal plain.

• Alluvial fan
• Alluvial plain (Coarse to medium subsurface deposits).
• Alluvial sand deposits
• Alluvial marine platform (medium to fine subsurface deposits).

Zabid alluvial aquifer :

Zabid water resources management district is underlain by an extensive alluvial aquifer which ranges in depth from 0-50m in the east, adjacent to the foothills to 200-300m at the coast.
The evaluation of the aquifer has been mainly controlled by the tectonics associated with development of the Red Sea graben. The aquifer comprising of cobles gravel, sand salt and clays. (DHV, M.R.,1988).
The aquifer is divided into two layers, the upper part is more permeable with a thickness of 100m and a lower layer with less permeability, extends to a depth of 350m.
The occurrence of the upper layer is associated with the drainage courses of the Wadi Zabid and Wadi Rima'a. The coarse grained deposits are inter-bedded with lenses and layers of intergrained motival. This is often characteristic of aquifers formed from coalescing alluvial fun deposits. Locally this produces semi-confined conditions, but the aquifer as whole acts as an unconfined system.

Aquifer production

The depth to water level varies according to the location:

• Near the foot hills in the east the groundwater level varies from 0-50 meters below ground level

• In the middle part of the district the groundwater level ranges from 70-120 m below ground level

• Near the coast the groundwater level ranges from 100-300 m below ground level.

The depth to groundwater level has been declined during the past 20 years (1985-2005) by about 30 meters especially in the first and second areas where extensive groundwater irrigation areas with an average decline of about 0.5-1.5m per annum.

Hydraulic gradient:

It varies from area to area according to location. In the alluvial fan areas it is about 0.01, in the central plain area it is about 0,005 and in the coastal zone is 0,001. The changes in gradients is mostly determined by, an increasing aquifer thickness, by sea level and the coast.

Hydraulic conductivities Varies conciderable, reflecting the complexity of the aquifer system. The ratio of vertical permeability and horizontal along Wadi Zabid and Wadi Rima'a channel varies from 0.007 to 0.12, and the ratio of permeability along the Wadi coarses to the permabilities normal to the Wadi course varies from 1-3 m/d (HWC).

Permeability of more than 60 m/day mostly occurs at the top (30-10m of the aquifer) gradually declins to about 30m/day at depths of about 100m.

Transmisivity :

Base on pumping test results, well logs and specific capacity data carried in the area by DHV (DHV, 1988), the broad range of transmisivity value was estimated as follows:

Fan areas less than 500 m2/d

Central plain 500-1000 m2/d and

The coastal zone 1000-2500 m2/d

Specific capacity :

In the area, the specific capacity ranges from 1-5 l/s/m with higher values at the Wadi channel and the coastal areas 1-8 l/s/m.

Specific yield :

According to DHV (DHV, 1988) mean value was 13%, although values ranging from 1-23% are reported from different surveys. However these are assumed values (HWC, IV volume , 1992).

1-6 Climate

Zabid water resources management district is an arid district typical of the Tihama region. It receives small amounts of rainfall during summer, with higher temperatures prevailing throughout the year. The Zabid W.R.M.D is in the vicinity of three large bodies of water which effects the climate**:** The Indian Ocean, The Red Sea and the Mediterranean Sea. They are sources of moisture for the passing air masses and they have an impact on the general atmospheric circulation (WRAY-35).

The presence of the Red Sea produces the so called Red Sea convergence zone (RSCZ) which contributes to the spring season (March-May). The light rains sometimes observed during the winter months of December and January are attributed to a similar convergence effect around the Mediterranean Sea’s. Mansonal winds rain that creat the inter tropical convergences zone (ITCZ) effect during summer causing the main rainy season. (July-September).

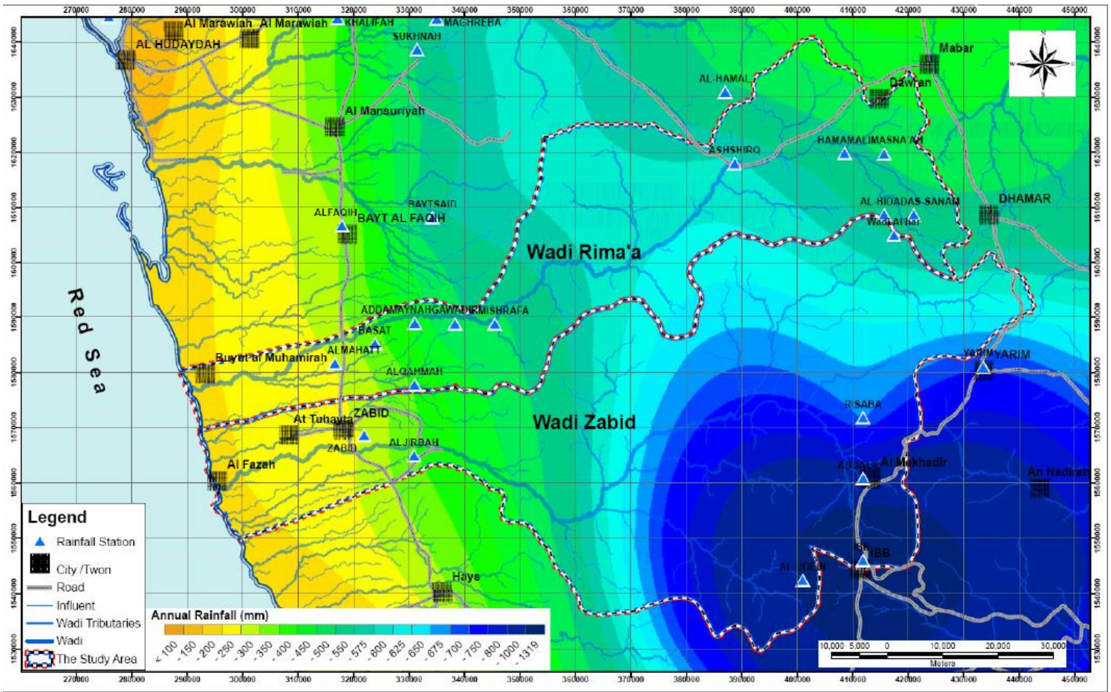
1.6.1 Rainfall :

Rainfall in Zabid water resources management district increases east ward due to the geographic effect of the mountainous areas. The rain fall patterns are influenced by both the Red Sea convergence zone effect (RSCZ) and the inter tropical convergences zone (I.T.C.Z) effect, which produce to main rainfall periods, one from March to May and the other from July to September.

Mean annual rain fall amount varies from < 100 mm in the western coastal areas to about 500 mm in the eastern foothills areas (DHV,1988).

Rainfall observations and measurements began in 1970 in the main Wadis (Zabid, Rima'a) and in the catchment areas of those Wadis. The annual rainfall stations have been established for different objectives by various consultants who carried out water resources studies in Zabid district from the period 1970 to 1984. There was a shift towards automatic rainfall stations during the implementation of Tihama Basin Water Resources Study (TBWRS) 1984-1988 and these stations are still operated by Tihama Development Authority (TDA). The catchment area of Zabid water resources management district is an arid to semi arid region and it receives more rainfall than the Tiham plain due to the geographic effect of the mountainous areas (high elevation). The catchment area receives rainfall in two seasons : spring and summer.

Mean annual rainfall amount varies from < 500 mm in the middle catchment area and in some parts of the upper catchment area (Dhawran Anis, Dhamar) to 1000 mm in upper catchments area (Ibb, Gibal Raymah). The rainfall stations were established at the same time as the rain stations in the lower plain, and were automatizide and they still observed by TDA (Table 1 & figure 3, 4).



1.6.3 Evaporation :

Evaporation values in Zabid water resources management district were calculated using the Penman reference which include the following parameters from the Al-Gerbah Hydrometeoroligical station:

• Mean monthly temperature
• Mean monthly humidity
• Sunshine duration
• Wind speed

Seasonal variation ranges from 4-7 mm/day and the annual total is about 2000 mm (DHV, 1988).

1.6.4 Humidity:

Humidity varies throughout the year. The humidity and other parameters in the study area were measured using the Zabid Hydrometeorological stations.

The mean monthly humidity is 60-75%. Figure 6 illustrate the mean monthly of humidity, while Table 2 shows the different parameters which are measured by the Al Gerbah meteological station .

1-7 Surface water

Surface water in the Zabid Water Resources Management district consist of wadi flows which reflect the seasonal rainfall pattern in the catchment area.

The catchment area of the Zabid district includes two main Wadi catchments - Zabid and Rima'a, these catchment can be divided into upper, middle and lower sub catchments. The lower part of the catchments are located in the Tihama plain.

The flow regime is determined by the rainfall and the groundwater storage /out flow in the middle and upper catchments.

The contribution of those components determine the flow downstream. The Tihama plain (lower, sub-catchment) is considered to be minimal .

The area of the upper and middle sub catchment is 8757 km2.

The area of the lower sub catchment (Tihama) = 2242 km2.

The total catchment area = 10999 km2. (HWC, & DHV).

Discharged volumes:

Monitoring and measurements of volume discharge in both main district Wadis (Wadi Zabid and Wadi Rima'a) started in 1970 and in 1975 by various consultants who worked for the TDA wadis development projects. These monitoring stations are automatically and still tacking place in two locations by TDA (Alkolah Station in Wadi Zabid and Almishrafah station in Wadi Rima'a).

Surface water flows are extremely variable. Long period of low flows may be alternated by the occurrence of floods with a short duration but a high discharge.

Discharges during low (Base) flow conditions are typically in the order of 1-5 m3/sec.

During the floods the discharges may rise to several thousands m3/sec. (DHV, T.R.2).

High flood peaks are occurs in the months April, July and August. The wettest season is usually July to October where the Wadis surface flow discharge volumes reach two third of the total annual flow volumes.

Floods in comparison with base flow volumes are in order of two thirds of the total flows. The water from the Wadis that is not lost by evapo-transpiration in the spate irrigation zones feeds the groundwater system of the district and continues moving towards the sea underground. In the past this water was finally discharged into the Red Sea (by groundwater outflow).

Irrigation practices have created the second important discharge component. The evapotranspiration of irrigation crops and sediment transport tends to be extreme during high flows.

3-2 Salt water Intrusion

The salt water intrusion happen when there is a reduction in the fresh water head and flow at the sea water interface. This commonly occurs when there is over pumping or insufficient groundwater recharge of an aquifer in the coastal zone. This phenomena happened due to the differences in density of sea water and fresh water .

Fresh water has a density of 1.0g/cm3 whilst salt water is slightly denser: 1.025g/cm3. Because of this fresh water floats on top of the sea water. The underground boundary that separates the fresh water layer from the salt water is not a sharp boundary line. In reality, this boundary is a transition zone of brackish water (fresh/salt mixture) as shown in the figure 27.

The mathematical formula (Ghyben-Herzberg Relation) for the fresh to salt water relationship is:

$$H = \frac{\rho_f}{\rho_s - \rho_f} \ x\ h = 40\ x\ h$$

Where

H is the depth of fresh water below sea level

h is the depth of fresh water above sea level

ρs is the density of salt water

ρf is the density of fresh water

According to this relation, if the water table in an unconfined coastal aquifer is lowered by 1 m, the salt-water interface will rise 40 m.

In The studu area, especially in Butut Al Muhaimirah, Ma'abar Al Gah, Ashwatebah and Assafariah in Wadi Rema'a and Al Fazah, Al Matinah and Al Noktah in Wadi Zabid is greatly influenced by many of borehole and dug wells whish is over pumping to abstraction water for human and agriculture uses. Yet the seasonal fluctuations in rainfall also greatly influences this zone. These wells that penetrate deeply within this transition zone results in sea water intrusion.