Assessment of Potential Water Resources in Abyan Area- Southern Yemen

Dr. Hatem Abdel Rahman Saied Ahmed Ewea[1]

Department of water resources, faculty of meteorology, environment and arid land agriculture science, King Abdul Aziz university, P.O. Box 80208, Jeddah,21589, Saudi Arabia

Hewea1136@gmail.com

الملخص العربي

تلقى محافظة أبين اهتماما خاصا من حكومة الجمهورية العربية اليمنية نظرا لكثافتها السكانية ، وأهميتها الاقتصادية ، وتعتبر دلتا أبين أكثر المناطق الزراعية الواعدة في جنوب اليمن ، و نظرا لأن المياه تعتبر هي المحدد الأساسي لهذه التنمية ، كان الهدف الأساسي من هذا البحث هو تقييم الموارد المائية المتاحة في المنطقة وقد أظهرت المباحث الحقلية المكثفة ، وتجميع وتحليل بيانات الأمطار ، والسيول ، والمياه الجوفية ، وعمل ميزان مائي لنظام المياه في منطقة الدراسة ، أن متوسط الأمطار السنوي يتراوح بين ٢٥٠ – ٣٧٠ مم ، وأن مقدار المياه السطحية قد وصل إلي ١٩٠ مليون م٣ ، كما أن مقدار الشحن الجوفي للخزان الجوفي قد وصـــــــــــل إلى ٥٦% منها ، ولضمان استمرارية التنمية الزراعية في المنطقة فإن المسحوب من مياه الآبار يجب ألا يتعدى ١٠٧ مليون م٣ سنويا .

Abstract

The development of the Abyan governorate receives special attention from the Government of Yemen due to its population density and economic viability. Abyan delta can be considered as the most promising area for agriculture development in southern Yemen. The availability of suitable water supply is crucial to such development. The main objective of the present study is to assess the potential water resources of the Abyan delta to satisfy the demand for agriculture development as well as the increasing domestic and livestock demands. Comprehensive investigations and field survey were carried out for rainfall, runoff, and groundwater resources. The water balance calculations indicated the potential surface water supply is 190 million m^3/year. Of which, the recharge account for about 56%. Consumption of indigenous water resources should not exceed the such potential for the sustainable development in the study area.

1. Introduction

The government of Yemen concerns with the development of the agriculture sector and raising the living standards of the farmers and rural community. The development of more land resources for agriculture as well as meeting the increasing domestic and livestock demands will be possible if adequate water supplies in quantity and quality are made available.

The Abyan Governorate is located at the southern part of Yemen. It extends for about 280 km along the Gulf of Aden coast with in land varying depth from 30 to 70 km. Abyan Governorate comprises of three main basins, Wadi Bana, Wadi Hassan and Wadi Ahwar. The former wadis; Bana and Hassan have large catchment areas of 7400 and 3200 square kilometer respectively. The runoff accumulating at the lower end of both wadis are drained to the combined Bana and Hassan Delta and designated as the Abyan Delta. Abyan Delta is a vast plain with its highest point in Bateis (around 170 m asl), where Wadi Bana enters. The

[1] Hatem A. S. Ewea on leave from department of civil engineering, Faculty of engineering , Azahr university, Egypt

distance from the apex of the Delta to the gulf of Aden is approximately 30 km, while the base of the Delta is about 20 km long. It is bordered in the north and the north east by high mountain chains (from 700 to 1000 m).

The present study aims at assessment of the potential water resources in Abyan delta. Such delta is considered a vital source of water for irrigation and water supply purposes. it is the most important aquifer in the southern coastal plains. In addition, it is the most promising area for agriculture development in Yemen; Figure (1). Awareness of the real potential water resources in such area is a prerequisite for sustainable development.

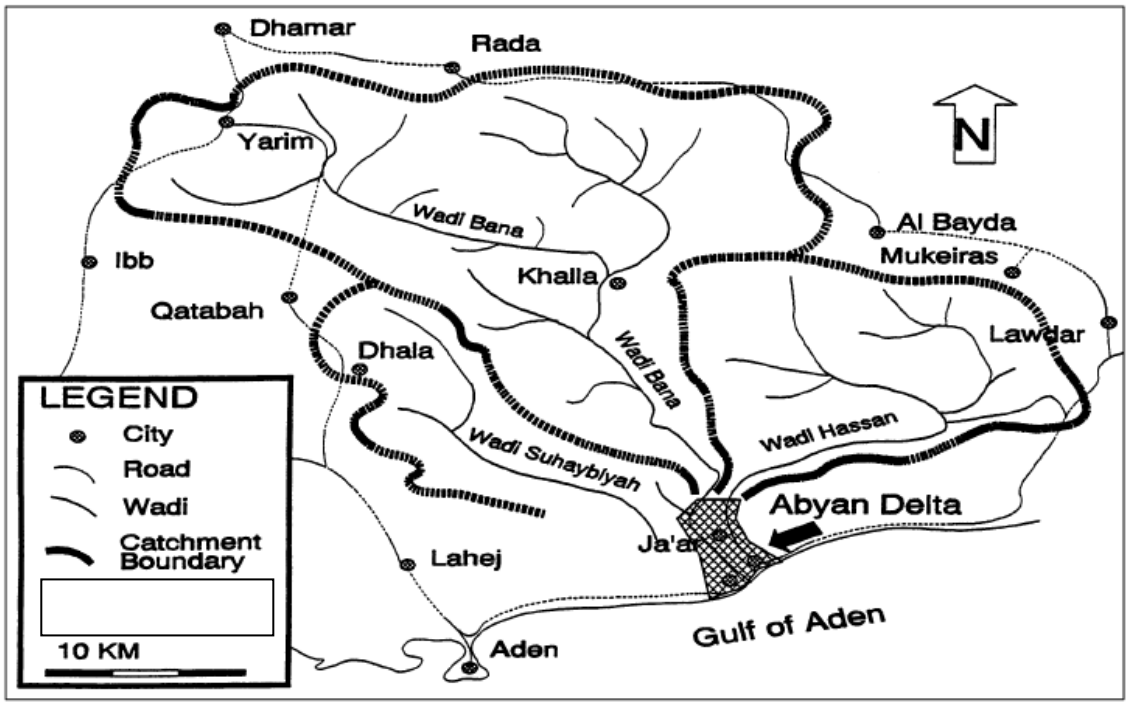

Figure (1) Location of the Study Area

Collecting and evaluating all available previous reports and studies pertinent to the study area over the past years were carried out. In reviewing the previous studies, it was found that several studies are dealing with water related affairs with minimum integration and coordination. So, information obtained during field trips included inspection of some metrological stations, runoff stations and conservation works, and wells.

Comprehensive investigations and field survey were carried out for rainfall, runoff, and groundwater resources. Long discussions with those involved with the collection of data in the Ministry of Water and Environment (MWE) in Aden and Ministry of Agriculture and Irrigation in Aden and Zungbar. Personal communications with the local inhabitants in many districts has been made to set up the present conditions Extensive analysis has been made on such information and investigations. Relying on the above, quantitative evaluation of indigenous water resources has been performed.

2. Catchments' Rainfall

The large catchment areas of wadi Bana and Hassan extend upward and drain high mountainous ground. Most of the rain falls in the mountains and foothills on which the mean annual rainfall is probable in excess of 1000 mm. The mean annual rainfall on the costal plain ranges from only about 50 mm at the coast to more than 700 mm at the mountain edge; 30 to 50 km in land. However, the direct annual rainfall on Abyan delta is very low and hardly goes beyond the 100 mm per year.

Several studies have attempted to drive relationships between mean annual rainfall and altitude as an aid to drawing isohyets. Groundwater Development Consultant (GDC) (1980) attempted to relate the mean annual rainfall and altitude for 28 rainfall records. They found that although there is a general tendency for rainfall to increase with altitude, the correlation between rainfall and altitude is overall not very great except perhaps in the west.

Within the mountainous area of Abyan' catchment, little or no rainfall can be expected normally in winter months. Even near the southern edge of the study area, rainfall can only be expected in July/September, and less consistently in April/June. Further in land, the likelihood of significant rainfall in April and June increases, although rainfall before April and September is unusually expect in high ground around Ibb.

Mean Annual rainfall of wadi Bana and Hassan are 370 and 250 mm respectively. Such depth of rainfall constitute annual volume of water of 2738, 800 million m^3 respectively. Although, both wadis have a large catchment extending upward to the areas of high rainfall, rainfall is insufficient for rain-fed agriculture in the delta of Abyan.

3. Surface Water resources

Major floods usually occur in both summer and autumn seasons (Seif and Kharif, respectively). The Kharif irrigation season (July-October) is the more important agricultural season. It receives most of the flood volumes . According WS Atkins and Partners (1984), both seasons accounted for 90% of the annual runoff, while 65% was accounted for the Kharif season alone. The Seif season (March – June) is less rigidly defined.

From the point of view of potential water resources utilization, the volume of surface water produced by a catchment during a year, a season or any other laps of time is extremely important. The mean annual runoff for the 16 year of record for wadi Bana is 170 mm, or 7.4 % of the estimated catchment' rainfall. Annual runoff volume Wadi Hassan has estimated by WRAY-35, (1995) at 41 mm. Such depth of runoff constitute annual volume of water of about 1258, 131 million m^3 respectively

4. Groundwater Resources

4-1 Water bearing horizons

The unconsolidated fills within the wadi' channels and plains in both wadis represent the main groundwater potential. As appears to be typical for such

catchments originating in the Highland and Midland areas, GDC (1980) concluded after detailed investigation that no significant water bearing horizons exist that could be developed to yield reliable supplies. Wadi fills, terrace deposits and fractured development in the underlying basement contained inadequate storage for sustainable supply.

At the mouth of wadi Bana-Hassan Quaternary aquifer of delta Abyan is situated. It is actively recharged by these wadis, partly by subsurface flows (underflows) via the interconnected wadi fill aquifers. In Abyan delta, the distribution and character of the alluvial deposits varies across the delta. Drilling activities for the Greater Aden well field in the inland delta have shown the existence of clear palaeo-channels which contain deposits of higher permeability but which give rise to complex and variable aquifer hydraulics. Aquifer parameters are provided in Negenman, (1995) . The storativity of the alluvial is not well defined. Values ranging between 1 and 8 % were derived from the Aden well field tests which are based on 3-day testing periods. The long term storativity may be somewhat higher. Transmissivities of the Quaternary are thought to vary from 300 to 10000 m^2/day. The sandstone transmissivity are estimated to be several orders of magnitude lower.

4-2 Recharge

Rainfall and the resulting surface runoff furnish the prime sources contributing to groundwater recharge. The contribution of rainfall on the delta of Abyan may be neglected as a source of recharge. Virtually the upper mountains in the Abyan Governorate receive the highest annual precipitation. These mountains dissected by the deeply incised valleys draining runoff water into the middle plateau and finally towards to the Gulf of Aden.

Direct Recharge is taking place into the distinct fissures, weathered bare rocks of such mountains. Another part infiltrates when wadi channels are filled with water during heavy rainfall.

Flow onto the delta occurs as groundwater baseflow along each main wadi course and also as flood and baseflows within each wadi channels; Sogreah, (1981). The surface flows entering Abyan delta are also diverted into a network of canals distributing water for irrigation which, therefore, increase the area of potential aquifer recharge.

The assessment of groundwater recharge is much difficult. It has to be estimated by indirect methods, and lack of reliable data is usually a severe constraint. The resulting estimates are of variable reliability and generally not very accurate. A conceptual model for estimating the recharge was used in section 5..

4.3 Discharge

Groundwater abstraction for irrigation is the dominance form of the groundwater discharge. A great number of hand dug wells are reported to be operational in the study area, in addition of a considerable number of tube wells which used especially in Abyan delta. Generally, abstractions for irrigation increase particularly in the southern part of Abyan delta suggesting the poor reliability of irrigation of surface water in such area. This is a reflection of the insufficient

supplies of spate water throughout most of the area. Wells are used also for domestic supply and livestock.

The various studies have provided conflicting figures concerning estimate of average annual discharge. It ranged between 104 Mm^3; Sogreah, (1981), 70 Mm^3; Atkin, WS (1984) and 87 Mm^3; WRA- 35 (1995). Although the data available at present is not enough to support one figure, there are evidences from other investigators ; Bauman et al, (2003) and Steensma et al., (2004) that depletion of groundwater in Abyan delta is taking places severely in coastal zone.

4.4 Water Level Changes

Figure 3 compare the static water level (SWL) of some wells inventoried in 2003 with that observed in these wells in 1997, 1998, 1999, 2000, 2001 and 2002 by Ministry of Water and Environment. Most of the apparent changes in SWL between 1997 and 2003 may be attribute to seasonal fluctuations rather than long term changes. Indeed, it should be noted that the lower values of SWL observed usually in wells close to a wadi channel or canal. Most if not all the apparent decline in SWL that could be reported in a certain time clearly affected by recharge from recent floods. The static water level has 'recovered' in some representative wells in Abyan delta.

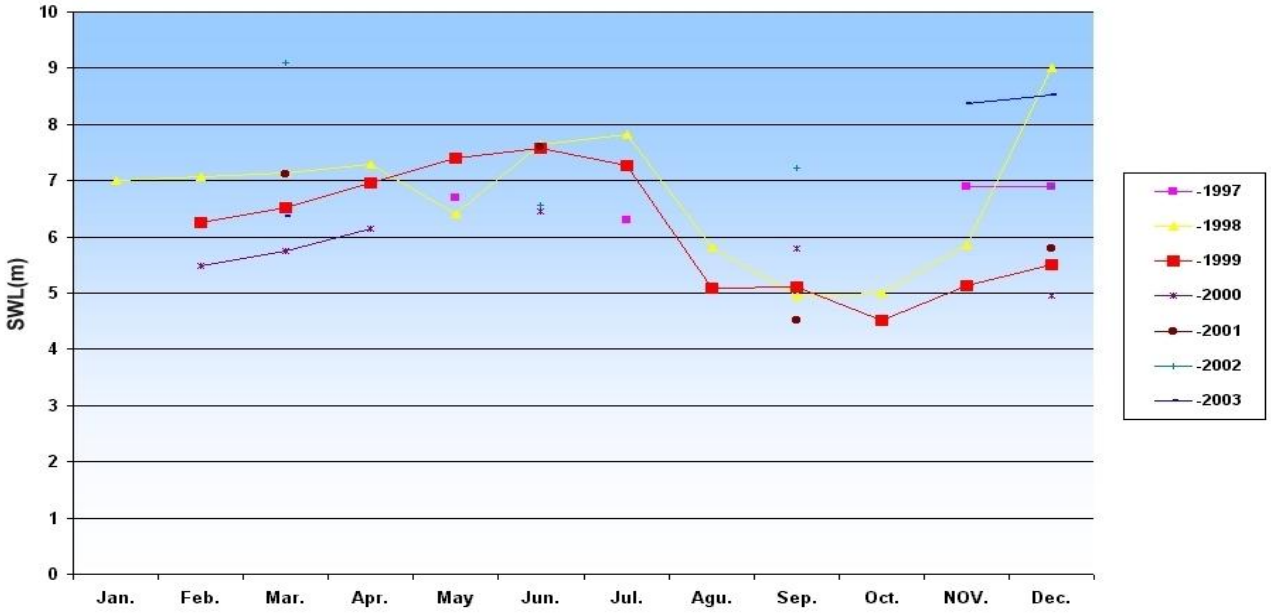

Figure 3 Water Level Fluctuations in El Koblya well in Abyan Delta.

4.5 Quality Changes

Groundwater mineralization is remarkably high in Abyan Delta compared to other deltas and coastal zones in Yemen. The spatial distribution of groundwater quality across delta Abyan has been mapped in some details in Figure 3. The observed distribution reflects the inferred patterns of groundwater recharge in that the lowest salinity groundwater occur in the vicinity of irrigation canals and diversions. Saline groundwater (in excess of 4,000 µmhos/cm) occurs away from the delta and in the immediate vicinity of the coast. These are separated from the low salinities by steep transition gradients which are reported to vary spatially in accordance with seasonal recharge.

A comparison of the 1997 and 2003 TDS values for in 36 Wells in Abyan delta suggests deterioration in some wells. Many of the TDS values had recovered to approximately their 1997 level. It appears that whereas there has been little change in the quality of groundwater in the upper delta (less than 3000 ppm), there have been some deterioration of this quality in the lower part of the delta and in the North West direction range between 3000-8000 ppm.

5. Evaluation of water resources potentialities in Abyan delta

We will attempt using the date gained to determine the average balance of the delta Abyan. Wadi Bana, Hassan together with the smaller contribution of the Wadi Suhaybiah and Wadi Mah'aria drained to delta Abyan. The balance is expressed as follows:

$$\mathbf{Sw= W_L+C_L+F_A}$$

Where,

S_W= Surface water supply

W_L= Wadi losses , include conveyance losses and escapade below lowest off take

C_L= Canal Losses

F_A = Field application

Surface Water Supply (Sw)

In wadi Bana, we have used only that part of the records, which is most likely to be correct and discarded the rest, for the calculation of the average monthly and annual discharges. Most of the discarded recordes is incomplete. The average annual discharge of the wadi Bana at Batais is of the order of 170 Mm^3.

In wadi Hassan, a considerable proportion of the runoff from the upper part of the catchment is diverted upstream of the Abyan Delta to supply the Yeramis co-operative. In 1987, the cropped area of this cooperative was 1200 ha and consume an order of 20 Mm^3 according to Binnie et al, 1988. This is just over half the average flow of the Wadi Hassan estimated by assuming that on average, the runoff in the Hassan catchment is like that in the Bana catchment, equivalent to 7.4 % of the rainfall.

Therefore, it may be tentatively assumed that the average annual flow of the Wadi Hassan reaching the Abyan Delta is only 15-20 Mm^3 and together with the smaller contribution of the Wadi Suhaybiah and Wdi Mah' areas add an average of 20 Mm^3 per year to the 170 Mm^3 provided by the Wadi Bana

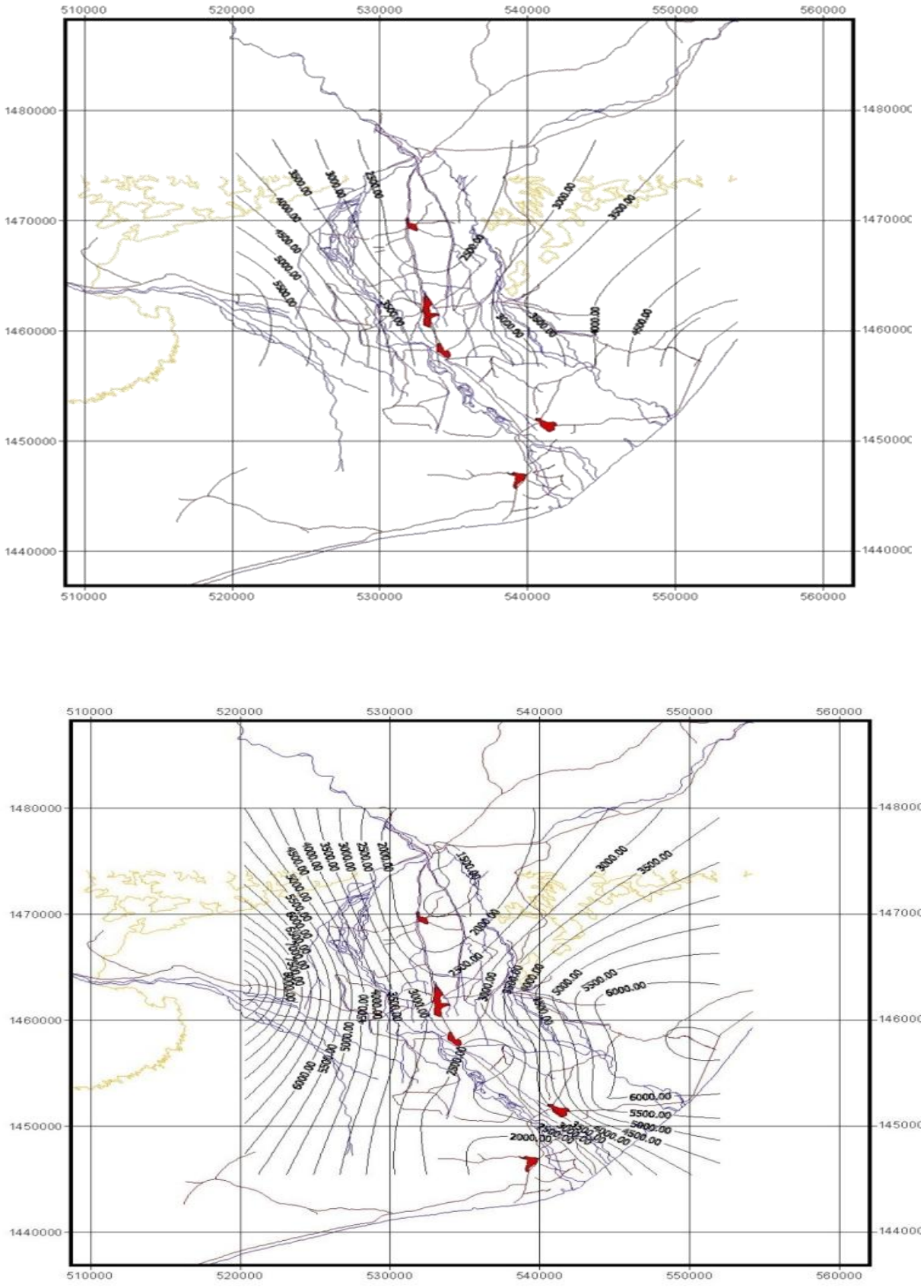

Figure 4 The Spatial Distribution of Groundwater Quality Across Abyan Delta in 2000 and 2002

.

Losses from Wadi Channels (W_L) and Canals (C_L)

At present, relatively little is known about the losses from wadi channels and the canals. Attempts to measures these losses by simple inflow-outflow measurements in selected reaches of these watercourse have proved inconclusive, since many of the losses associated with unsteady flows are purely transitory. Initially, such losses are expected to be very high, particularly in water courses which have not received flow for more time, as a considerable volume is taken up in channel and bank storage. This applies particularly to the minor canals which may be used only once each season. Since some but not all initial losses may be returned after the flow reaches its peak, measurement should really be taken over the entire duration of the flow event. However, the uncertain timing of such events makes this very difficult to arrange and in any case, a large number of such events and water courses need to be sampled to evaluate the losses in the system as a whole.

GDC (1980) calculated loss rate relying on a 9.6 km reach of wadi Zabid in Tihama and a measured conveyance losses in a 3 km reach of wadi Rima' also in Tihama. It was found that the average annual conveyance losses were 25% of 150 Mm^3. For monthly flows, these losses were as follows:

Monthly flow (m^3/s)	Loss rates	
	% per km	M^3/s per km
5	4	0.2
10	3.3	0.3
50	1.6	0.8
80	1	0.8

The measured conveyance losses in wadi Rima' was 0.15 m^3/s per km. However, this was at low flow, and under flood conditions the losses were expected to be of the order 1.5 m^3/s per km.

In order to evaluate how much of the flow of the wadi Bana at Bateis is accounted for by conveyance losses from the wadi and the canal system, GDC (1980) calculations show that in an average year, the losses from the wadi channel and the canal system could each account for 30-35 % of the flow at the head of the delta.

Field Application (F_A)

Al-Amiry, 2005 measure the return flow in western Saudi Arabia and found that the irrigation return flow percolated below the root zone is 41% of the total application and 6% of the total application is stored in the unsaturated profile of 2 meter depth. On average, it has been assumed in Abyan delta that about 60% of the water applied to the spate irrigated fields is retained within the root zone. For unsaturated depth ranging between 4-8 m the net contribution to groundwater recharge could be considered about 20% of the original application.

Taking into account the additional water probably applied where the irrigation water has to be passed from field to field, the average application with the crops presently grown in the Abyan Delta has been estimated to be 625 mm or 6 250 m^3/ha ; MCE, (2006).

As a result of the recent survey carried by MCE, (2006) in 2005, the area of spate irrigation has averaged at 10700 ha. Therefore, the direct contribution of spate irrigation to recharge has averaged only about 67 Mm^3 per year. Nevertheless, the conveyance losses involved in distributing water to the fields provides an even greater contribution to recharge.

Item	Surface Water Mm^3/year	Groundwater Mm^3/year
Surface water supply		
Wadi Bana	170	
Wadi Hassan	20	
	190	
Wadi Losses		
Conveyance Loss (30-35 %)	61	49
Espcapage below Lowest offtake		
(5-15% to the sea)	19	10
Canal Losses (20-25%)	43	35
Field Application	67	13
	190	**107**

Results

The summary of various components of water balance in the delta abyan aquifer in million m^3/year is shown in the above table. Although, It is not seriously possible to go little beyond these figures, they show at least the feasible value range based on clearly established data. The figures indicate that the present the average annual recharge to the Abyan aquifer as 107 Mm^3 per year. Not all the water lost in the wadi channels and canals becomes groundwater recharge. Although a small amount is lost to the atmosphere by evaporation, a much larger volume is taken up by evapotranspiration.

Natural vegetation occurs along the wadis and uncultivated land, and date palms are scattered through the spate irrigated area. Also, there appear to be a considerable area of crops (mainly sorghum) planted in wadi channels and canals. Sorghum is also usually planted in fields which have not received a full

application of water. The crop is often confined to the lowest part of these fields and it is difficult to believe such fields are included in the irrigation statistics.

In view of the uncertain accuracy of some items in the surface water balance, the contribution of wadi and canal losses to groundwater recharge has been provisionally assumed at 80% of the total losses. Together with the recharge from fully irrigated fields (20%), the total recharge appears to account for about 56% of the surface water supply. Despite an uncertainty of up to 2 to 1 on some components not more, this balance constitutes quite progress for the knowledge base required for sustainable development in Abyan area.

6. Conclusion

The water balance calculations indicate the total surface water supply is 190 million m^3/year. Of which, the recharge account for about 56% which constitute only 3% of the average annual rainfall. To assure sustainable development, a total abstraction rate of 107million m^3/year from the delta aquifer should not be exceeded. such abstraction rate currently achieved through the ongoing agriculture practice. Reviewing the crop pattern in the delta to maximize the benefit of water is very essential.

Programs currently in force in Aden stress mainly on the development of more water supplies through more exploitation of the Abyan delta water. Strategic feasible plan should be developed to implement strict water conservation measures to maintain the abstraction and to optimize the use of good quality groundwater from the aquifer.

7. References

Al-Amri S, Nassir, (2005), Hydrogeological assessment of the Haddat Ash sham region, north east of Jeddah, Saudi Arabia, ph.D thesis, department of earth science, faculty of science, Birmingham university, UK.

Atkins WS, Binnie CJA (1984) Feasibility study for Wadi Bana and Abyan Delta Development project, Vol II, Annex A, Hydrology and water resources. Ministry of Agriculture and Agrarian Reform (MAAR), Aden

Binnie partners (1988) feasibility study for long-term wadi rehabilitation, volum I, main report, wadi Hadramaut agricultural development project (phase II), ministry of agriculture and agrarian reform, peoples's democrate republic of yemen.

Gilein Steensma, Jane Dettridge, Paul Hardisty, Komex Ambiental, Paul Bauman, Christine Cadman, and Richard Kellett (2004) , Geophysical delineation and groundwater modeling of saltwater intrusion in the republic of Yemen, 18 th SWIM, Cartagena (Spain), 31 may-3 June 2004.

Groundwater Development Consultant (1980) Wadi Tuban water management study, plan report-vol.

Misr consulting Engineers-MCE (2006) integrated rural development project, middle plateau-abyan province , abyan rural development project, ministry of agriculture and irrigation, finial report.

Negenman AJH (1995) Water resources Abyan Delta. Report WRAY-34. General Directorate of Hydrology (Yemen), Sana'a, and Netherlands Geological Survey (TNO), Delft

Paul Bauman, Richard Kellett, Gilein Steensma, Christine Cadman, Paul Hardisty and Jane Dettridge (2003) , Two case studies of geophysical delineation of salt water intrusion in Yemen, : wadi Hadramaut and the Tuban and Abyan deltas, the second international conferences on salt water intrusion and coastal aquifers-monitoring , modeling, and management. Yucatan, Mexico, March 30-april 2, 2003

Sogreah, (1981), Wadi Bana Hydrogeological Survey and Study: Final Report GAWSP

WRAY-35. (1995), The water resources of Yemen. A summary and digest of available information. The Republic of Yemen Ministry of Oil and Mineral Resources Mineral Exploration Board, Kingdom of The Netherlands Ministry of Foreign Affairs Directorate General of International Cooperation (eds), Sana'a/Delft.

Acknowledgement

Particular thanks to the Ministry of Agriculture and Irrigation for financial support and for the Ministry of Water and Environment in Aden for their assistance. I am greatly indebted to the Misr Consulting Engineers Office (MCE) for enabling me the chance to carry out this work.