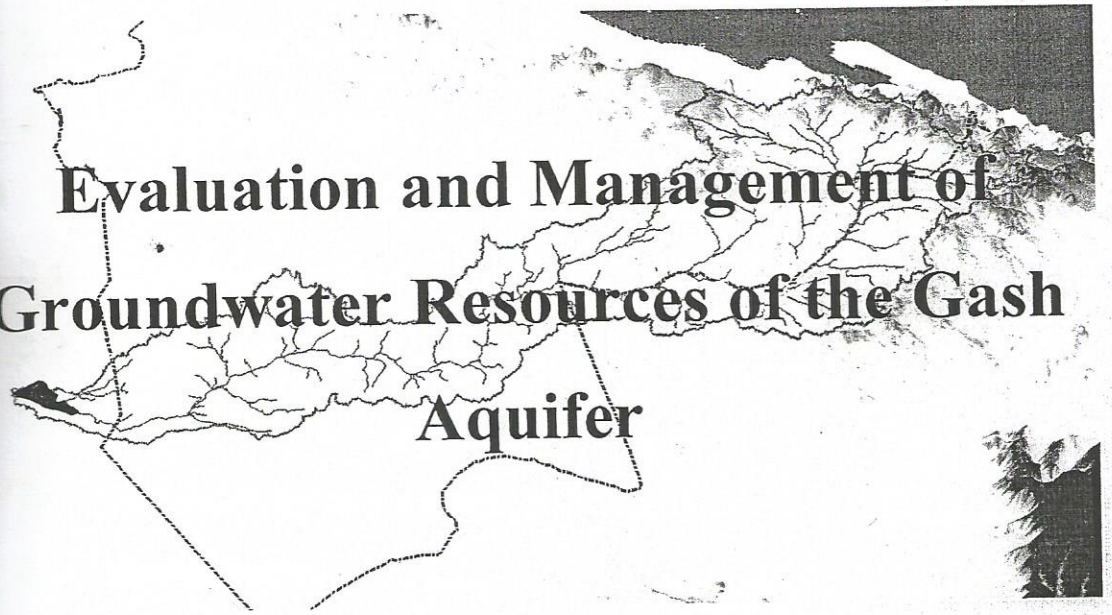
NILE BASIN INITIATIVE

EASTERN NILE SUBSIDIARY ACTION PROGRAM (ENSAP)

EASTERN NILE TECHNICAL REGIONAL OFFICE (ENTRO)

NCORE Special Study

Evaluation and Management of Groundwater Resources of the Gash Aquifer



Draft Final Report

University of Khartoum

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1 INTRODUCTION

1.1 Overview

The Gash is a trans-boundary seasonal river that originates in the Ethiopian and Eritrean highlands and flows to the eastern parts of the Sudan (Figure 1-1). It has a catchment area of 40000 km2 which is distributed between Eretria, Sudan, and Ethiopia and as 21400 km2, 9600 km2, and 9000 km2 respectively. The river Gash has a length of 200 km and a slope of approximately 200 cm/km. The annual river discharge fluctuates between 400 and 1200 MCM with mean annual discharge of 680MCM. Occasionally, the higher discharge rates of the river lead to over bank flooding that cause severe damage to buildings and farms of the Kassala town, the capital of the Kassala State, and the river Gash delta agricultural areas. The Gash River is considered a source of frequent terror to the inhabitants of Kassala on both sides of its banks.

The Gash River in Kassala area is underlain by the Gash aquifer which is considered as a most important source of water supply for both domestic and agricultural use. The aquifer is formed of the layers of recent deposits which are mainly sandy and gravely deposits. These layers are very pervious and permeable. Some less pervious layers are found which are composed of clay and/or clayey sands. The water bearing alluvium deposits of the Gash basin are laid on the basement complex which is formed of impermeable gneiss and granitic rocks. Immediately on the basement complex rocks, some places are characterized by few meters thickness of weathered rocks which contain water but remain of less hydrogeological importance. The best aquifer is found along the banks of the Gash River, where it is composed of fine to coarse grained sandy and gravely deposits. Laterally, the alluvial pass into moderately less permeable deposits as a result of rapid facies change. Finally they wedge out against the impervious clay of the plain at the eastern and Western side of the aquifer (Figure 2).

The aquifer is mainly recharges from the river Gash during the flood season. Rainfall also contributes some amounts of recharge, but of less significant than river recharge. Discharge from the aquifer is mainly through pumping from storage for domestic and irrigation activities, with irrigation representing the major consumption. Irrigation is in the form of private horticultural farms with the areas known Southern and Northern Sawagi being the densest horticultural areas. Important produced crops are banana, vegetables and citrus fruits. Sorghum and oil crops are also found in the area.

1.2 Case Study Justification

Groundwater it is a key element for human settlement and sustained socioeconomic development in the Gash Basin. Demand for groundwater in the region has recently increased considerably and huge number of wells has been drilled in order to meet the needs for the implementation of agricultural and economic development. However, this huge development in groundwater is taking place in a rather unplanned manner leading to many problems such as overexploitation, reduction of reliable well yield, and deterioration of quality.

Recent studies on the Gash aquifer revealed that the aquifer is over-pumped resulting in serious aquifer depletion. Pumping is taking place in a rather unplanned manner and groundwater management is entirely lacking. Currently there is a very large number of wells operating in the area without any type of control. If this situation continues, serious consequences are likely to take place including reduction of reliable aquifer yield and deterioration of water quality.

The area was subjected to many studies in the past. Though these studies provide valuable hydrological and hydro-geological data such water levels, pumping rates, pumping test data, they did not look into the details of the water balance components, specifically the river aquifer interaction and estimation of groundwater recharge. Also, previous studies have not developed comprehensive plans for groundwater management in the area.

1.3 Objectives of the Study

The main objective of this study is to develop a comprehensive plan for groundwater management in the Gash Aquifer basin. This will entail the following:

- Development of a conceptual model for the aquifer comprising the aquifer hydrogeological boundaries, water balance components and any important hydrogeological features (e.g. River Aquifer interaction)
- Full development of a mathematical model to simulate the aquifer behaviour
- Use of the developed model to assess the impact of potential management scenarios on the groundwater within the basin
- Recommendation of sound policies for groundwater management within the basin.

2 METHODOLOGY

2.1 Overview

One of the main objectives of this study is to develop a mathematical model for the Gash Basin. Mathematical modeling is the ultimate tool for the analysis and simulation of groundwater resources as well as for their management. With the goal of developing a mathematical model for the groundwater basin, the study was divided into four complementary phases which are:

- Compilation and analysis of existing data on the Gash Basin and the project area
- Enhancement of the project database through field visits and data collection campaigns.
- Development of a mathematical model for the basin that include the Gash River.
- Simulation of the long term abstraction on the Gash Basing.

The first two phases are geared towards the delineation of the boundaries of the areas that are to be included in the model, development of a suitable conceptual model as well as the compilation and collection of the data required for the model development.

2.2 Study Region and Boundaries

The River Gash Basin extends from the Sudan Eritrea Border in a north westerly direction for about 60 kilometers. In spite of its small size this aquifer constitutes a major water source for the inhabitants of the town of Kassala and the surrounding villages. The hydrogeology of the area is dominated by the seasonal Gash River. Indeed the aquifer in the area is constituted by the alluvial sediments of the Gash River which are composed of fine to coarse grained sandy and gravelly deposits. The deposits extend for 100m to 6000 m from the river banks and its thickness vary from 5 to 60 meters. Groundwater occurs under free water table conditions at depth that vary from 2 to 30 meters depending on the proximity to the river, topography and pumping regimes in the area.

The Gash basin is bounded in all its sides by basement complex, thus underscoring the significance of the Gash River and its seasonal flow on the recharge rates and the groundwater levels within the study region, boundaries is shown in Figure 2-1.

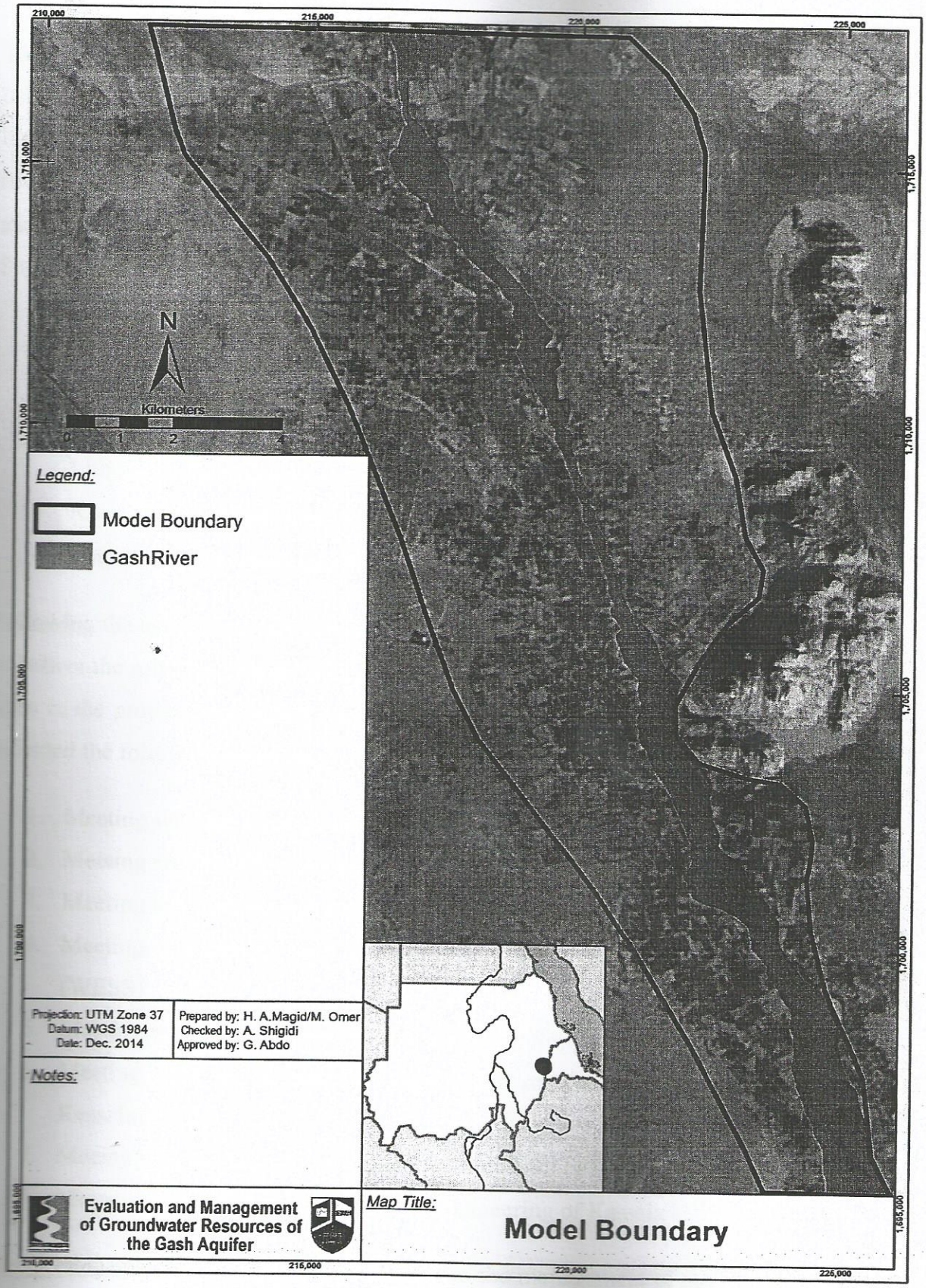


Figure 2-1: Model Boundary

2.3 Data Compilation

The Gash basin was subjected to a number of previous studies during the 1980s to delineate its boundary, study it hydrogeology and assess its volume. These studies provide valuable information pertaining to the geology and hydrogeology of the basin as well as an insight into its historical development. Existing information were also solicited from the different federal and state agencies such as the Groundwater Directorate, Gash Rehabilitation Unit, Water Supply Corporation, Ministry of Electricity and Water Resources. Collected data included:

- Reports of previous studies
- Well data including:-International number, Location, Coordinates (longitude-latitude), Depth, Static water level, Dynamic water level , Well yield, Pumping test data, Lithology, Chemical analysis results.
- River flow data and river stage for the Gash river
- Maps including: Geological map, Hydro geological map, Topographic Maps

Following the assessment of the compiled data and identification of the data gaps, a field visit to collect the missing relevant data and corroborate existing data was conducted by the study team to the project area during the period from 12th to the 17th of September 2014. The visit included the following meetings:

1. Meeting with the Director and staff of the Groundwater Directorate of Kassala
2. Meeting with the Director and staff of the Gash Rehabilitation Unit
3. Meeting the Director and Staff of the Gash Agricultural project
4. Meeting the director and staff of the Water and Environmental Sanitation Unit (WESS)
5. Meeting with the concerned staff of the Water Supply Corporations of the Gash
6. Meeting with the Minister of Agriculture of Kassala State (Acting Governor of Kassala State)
7. Meeing with the Director of the Horticulture Unit of the Ministry of Agriculture
8. Meeting with the Dean of Faculty of Engineering of Kassala University

The meetings discussed major issues relevant to the management of the Gash aquifer well as data availability. Two liaison officers were contracted to follow up on the data collection efforts which included:

- Groundwater level data
- Well Lithology Data
- Mapping Agricultural Areas
- River Stage and River Geometry

In the subsequent chapters of this report, preliminary data analysis will be made to develop a conceptual model of the Gash aquifer and the major inputs and output to the model.

The different phases of the project were divided into a number of tasks the breakdown of which is represented in a flow chart (Figure 2-2) that shows the various steps of the study methodology and their sequence.

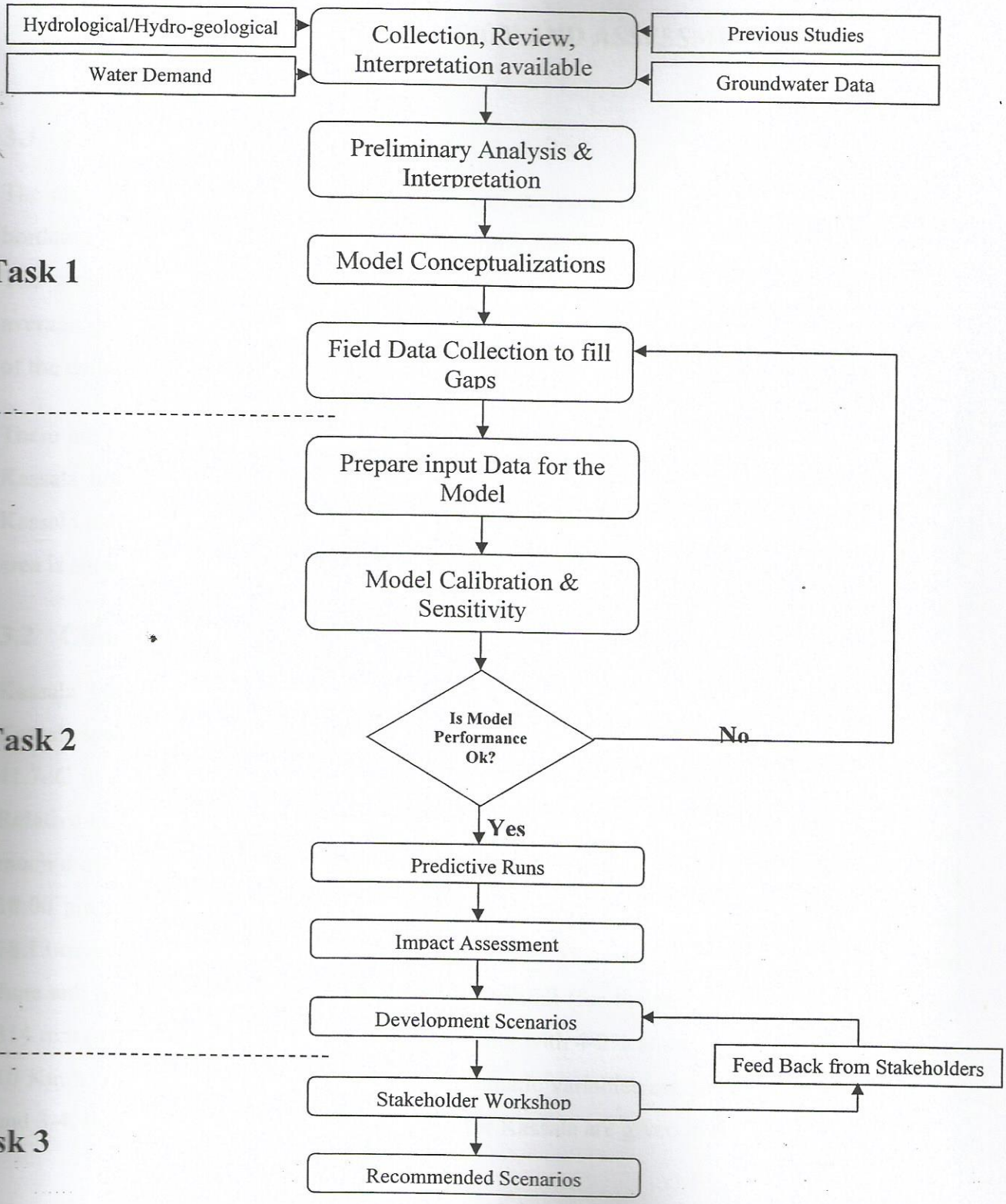


Figure 2-2: Study Methodology

3 DATA COLLECTION AND ASSESSMENT

3.1 .Topography

The area of the River Gash Basin is located in the north eastern part of Kassala province, bordered from the east by Ethiopia. It is generally flat will gentle slope to the NW direction. The ground surface elevation varies between 450m to 505m above mean sea level. The average ground surface elevation at Kassala town is 500m and it is about 450m at the centre of the delta.

There are three main mountains in the area: Jebel Kassala; the highest; located just close to Kassala town in the south east direction, Jebel Mokram about 2 kilometer north to Jebel Kassala and Jebel Gullssa in the southern end of the area. A digital elevation model for the area is shown in Figure 3-1.

3.2 Climate

Kassala has a tropical continental climate. The mean temperature on the plains around Kassala town amounts approximately 29oC. The average daily maximum temperature reaches 41.7oC in May, whereas the average daily minimum is 16oC mainly recorded in January. Relative humidity is inversely related to temperature whereas vapor content does not change much during the day. The mean annual vapor pressure is 18.3 and 16.2 mb at 6:00 am and 18:00 pm respectively. The mean value of evaporation was found to be 7.95 mm/day and 18.13 mm/day respectively at 6:00 am and 18:00 pm. The rainy season at the area is between June and September, and the mean amount of rainfall (for the period 1941 – 2010) is about 314 mm per year. Average mean relative humidity with 4-2% and annual mean wind speed is 10 Km/h. The annual variation of the main climatic variables are shown in Figures 3-2, 3-3 and 3-4. In addition tables of climatic normal for Kassala are given in Annex 1.

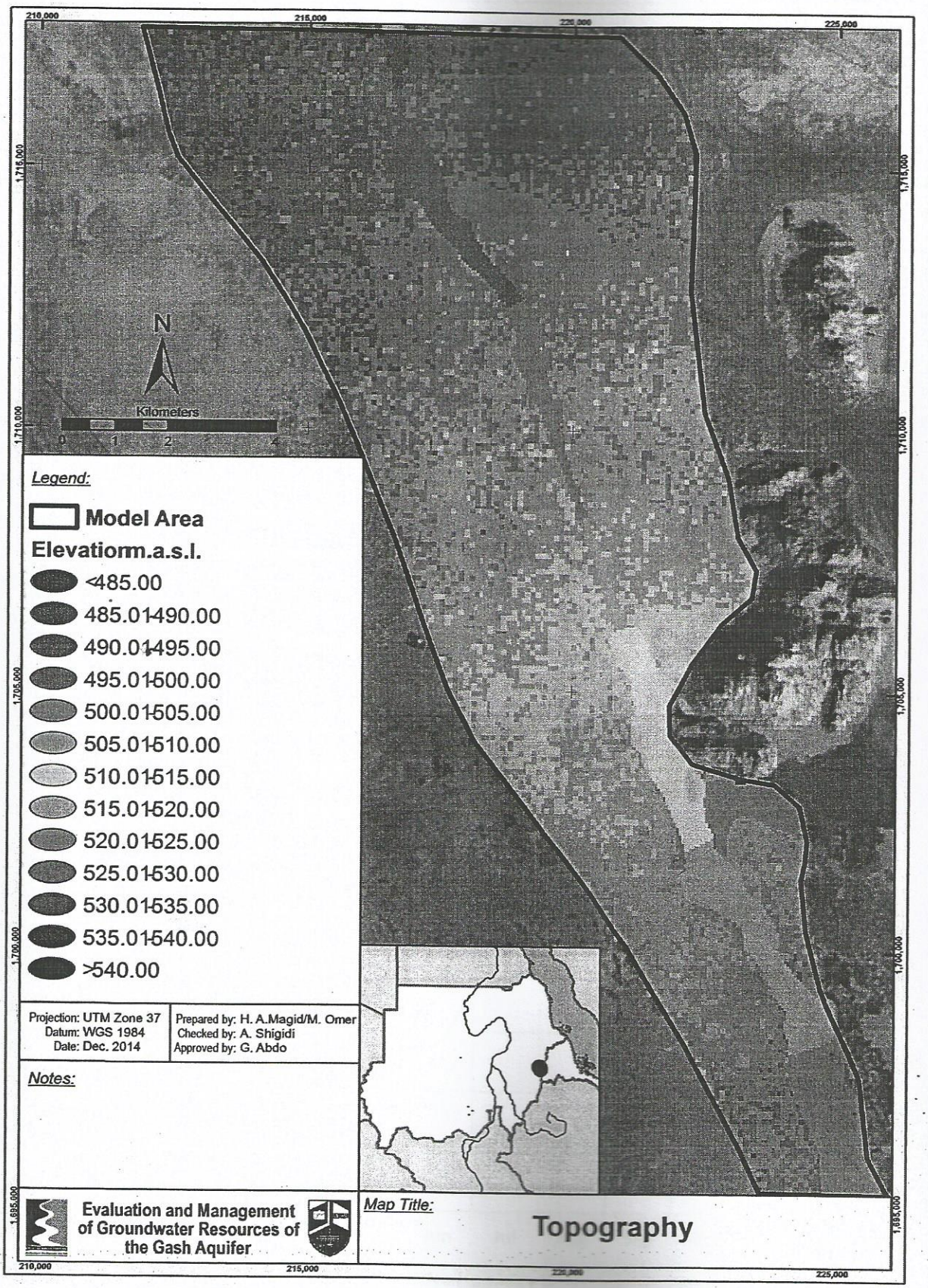


Figure 3-1: Topography

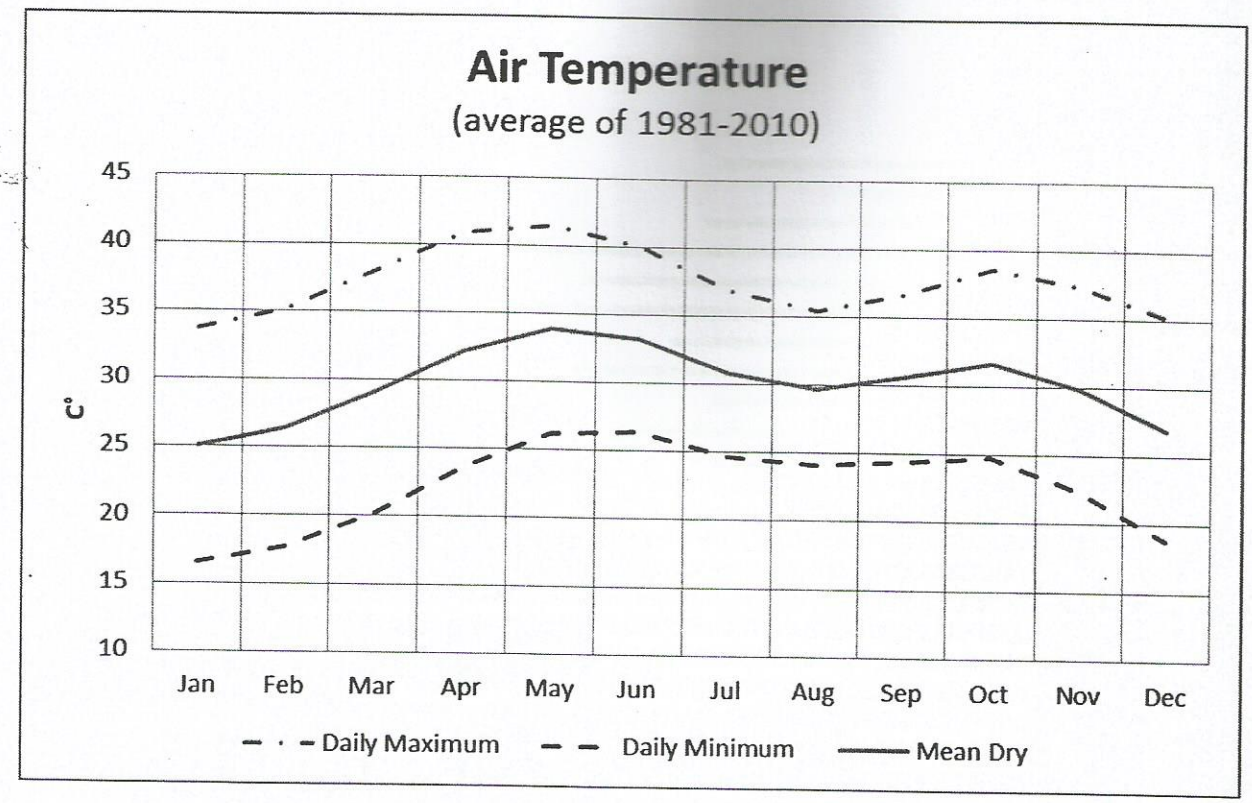


Figure 3-2: Mean Monthly Air Temperature for Kassala

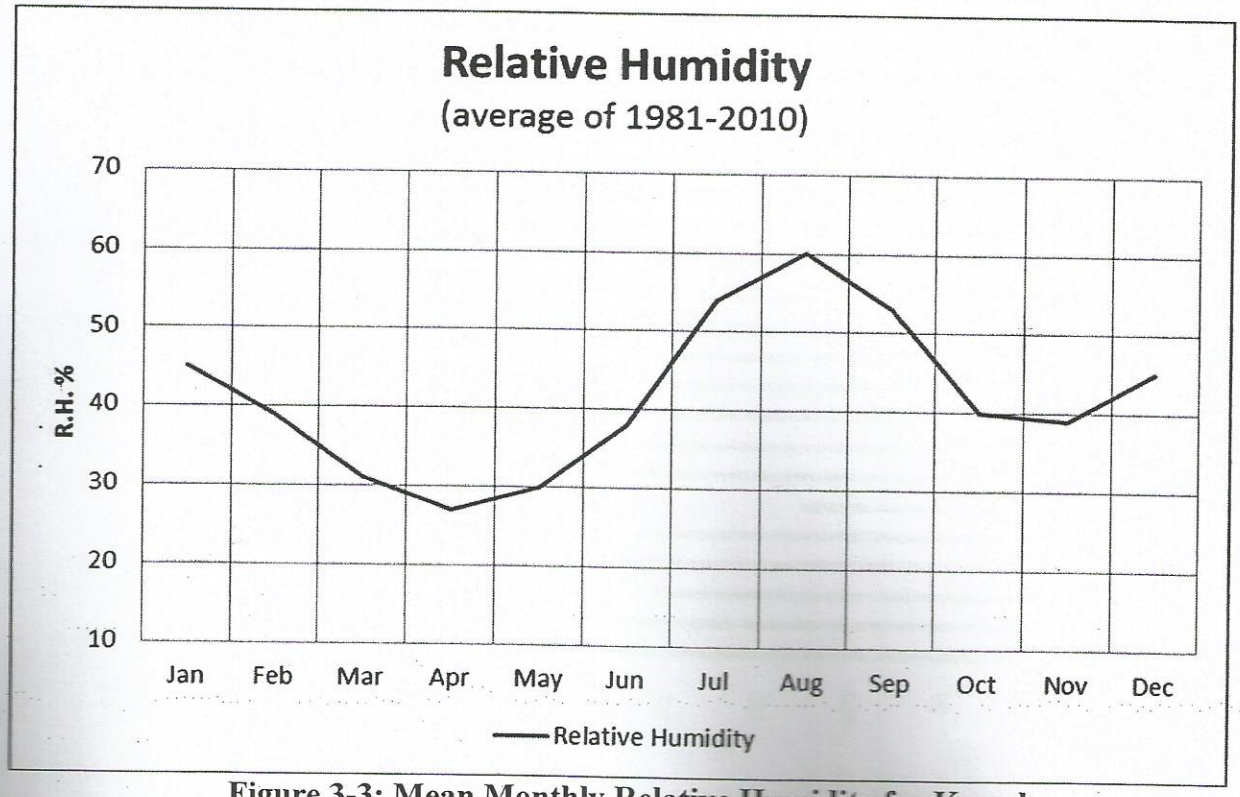


Figure 3-3: Mean Monthly Relative Humidity for Kassala

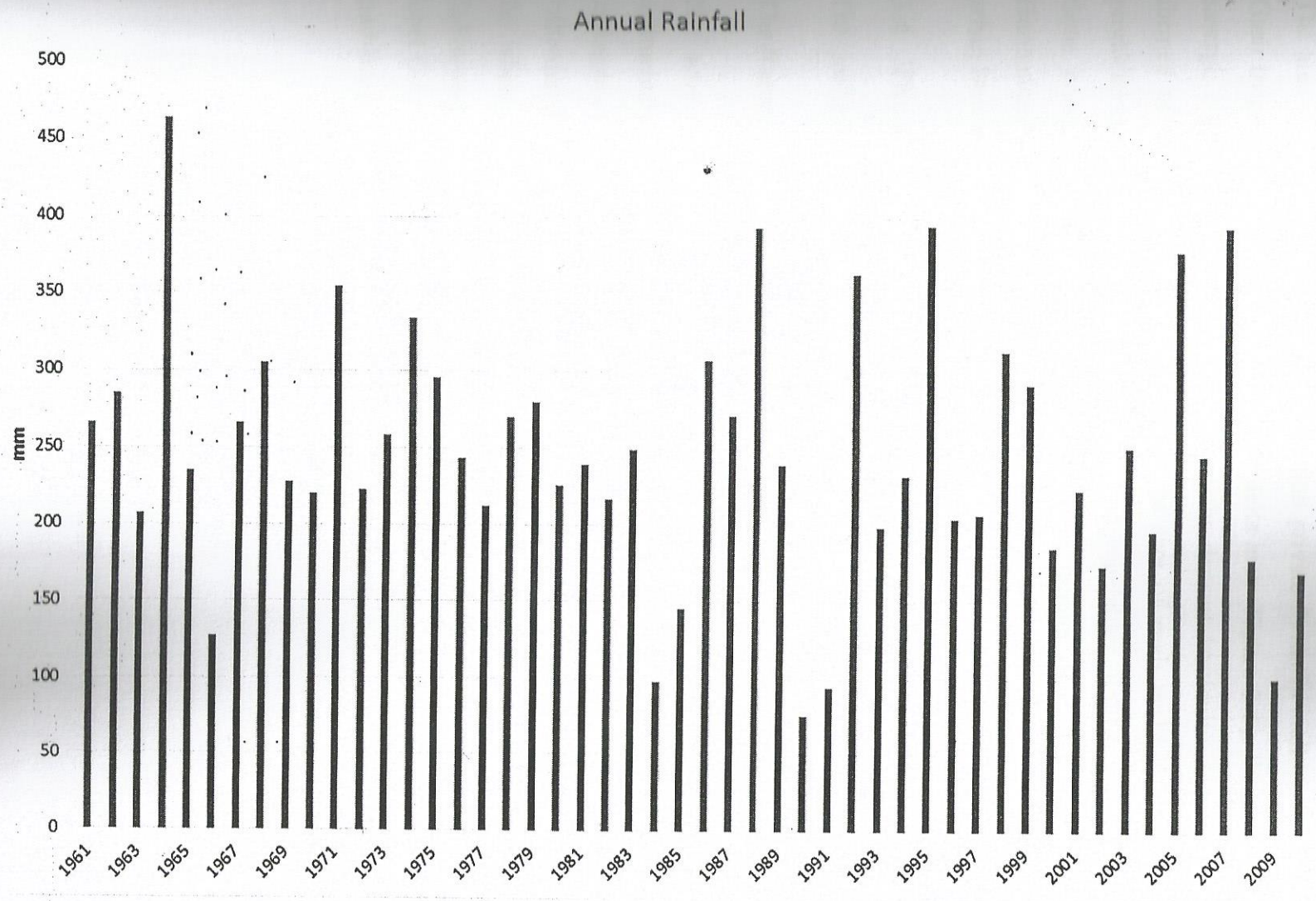


Figure 3-4: Annual Rainfall for Kassala for Years 1961 - 2010

3.3 Land Use

The area is characterized by the horticultural private farms in addition to the Governmental Gash Irrigation Project (50,000Ha) in the delta area (Figure 3-5). Within the area, southern sawagi; northern sawagi and el sabeel are the densest horticultural areas. These areas are formed of many private farms, the average size of each is 17.4 feddan. The important produced crops are onion, bananas, citrus and vegetables. Fruit trees are highly planted in these areas mainly grape fruits, lime, guave, orange, mango and mandarin. Area of Horticulture development area were estimated to be about 20,000 Fedaans (8,400 Ha) while urban Development accounts for about 70 Km^2 of the basin area.

3.4 The Geology of the Area

The geological setting, starting from older is as follows:

The Basement Complex

The term "Basement Complex" is used to include those igneous metamorphic and sedimentary rocks that are overlain by horizontal or sub-horizontal Paleozoic and Mesozoic sedimentary rocks or igneous rocks (Whiteman 1971). These are the oldest rocks in the area, following their formation the area was subjected to a period of prolonged erosion that reduced the whole area to a peneplain (ElTayeb Saeed 1969). In the area, Kassala district, the Basement complex is represented by Jebel Kassala, the very striking Jebel; Jebel Mokram and Jebel Gulssa. The Basement Complex rocks are composed of granitic and hornblende gneiss, marbles, granites and pegmatites and secondary quarts veins.

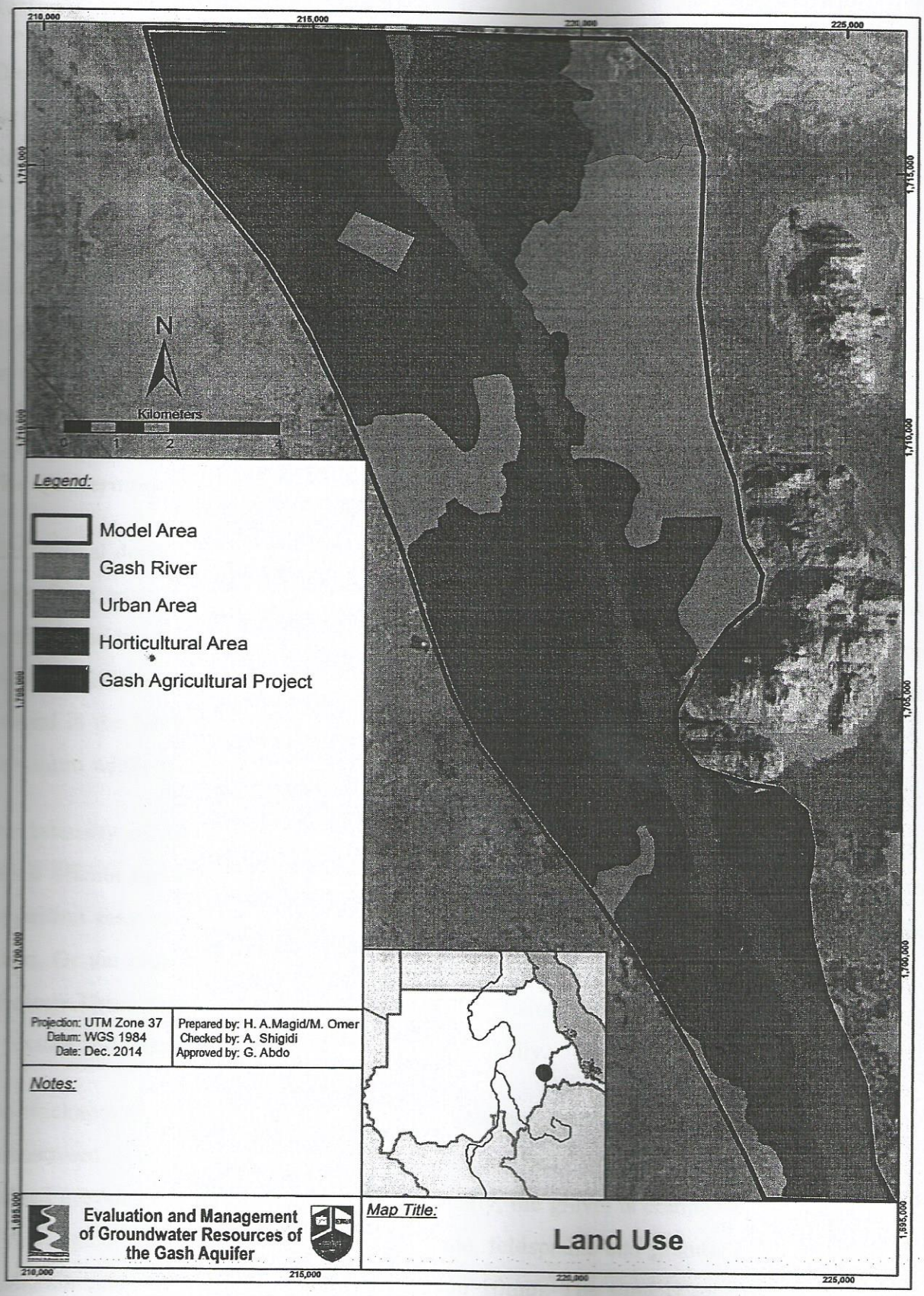


Figure 3-5: Land use

Tertiary – Quaternary Deposits

These are the Clays of the plain". The term has been applied by geologists of Sudan to the dark grey to dark chocolate – Colored clays that cover an extensive area between the White Nile and Ethiopia frontier. The clays of the plain overlain the Basement Complex, Nubian series and Tertiary Lavas, they are considered to be of Tertiary to Quaternary age. In the area of study the clays of the plain unit is found above the river flood plain east and west of the alluvial deposits It is grey to dark grey in color and consists of laminated loose to compacted clay, silt, sandy clay and sandy silt (El Tayeb M. Saeed 1968). The clays of the plain are the erosional products of the Basement complex rocks. It's thickness ranges from few meters to about 20 meters along the west side of the alluvial deposits.

The Quaternary Alluvial Deposits

The alluvial deposits of the area were formed by the Gash River and streams which join the Gash from east, during their annual flow. The river cuts into the clays of the plain and between the frontier and the town of Kassala, the alluvial sediments are restricted to a strip roughly 2 kilometers wide, which include the Gash River stream bed. From Kassala town and onward in the NNW direction the sediments attain the typical fan – like delta pattern with a maximum width of 25 kilometers.

The intensity of the storm causing the runoff controls the carrying capacity of the stream which affects the condition of transportation and deposition of fragments. As a result the deposition may vary between coarse materials during one flood to fine ones after another storm. Or the older deposition may removed in whole or in part and be replaced by a new lithology.These fluctuating conditions result in deposition of lens-shaped units which change in texture and character both horizontally and vertically.

The thickness of the alluvial deposits ranges between about 25m upstream to more than 50m downstream. They are composed of intercalating beds of unconsolidated coarse to fine grained gravels, sand, silt and clay. Lithologically, the gravel is composed mostly of angular to sub-angular quartz pebbles, however volcanic, feldspathic and granitic gravels are present. The grain size ranges from 2mm to more than 10mm. The sand is mostly well sorted and medium to coarse grained. It is composed of quartz. Feldspathic, micaceous and volcanic sands may present. A geological map of the area is compiled and shown in Figure 3-6.

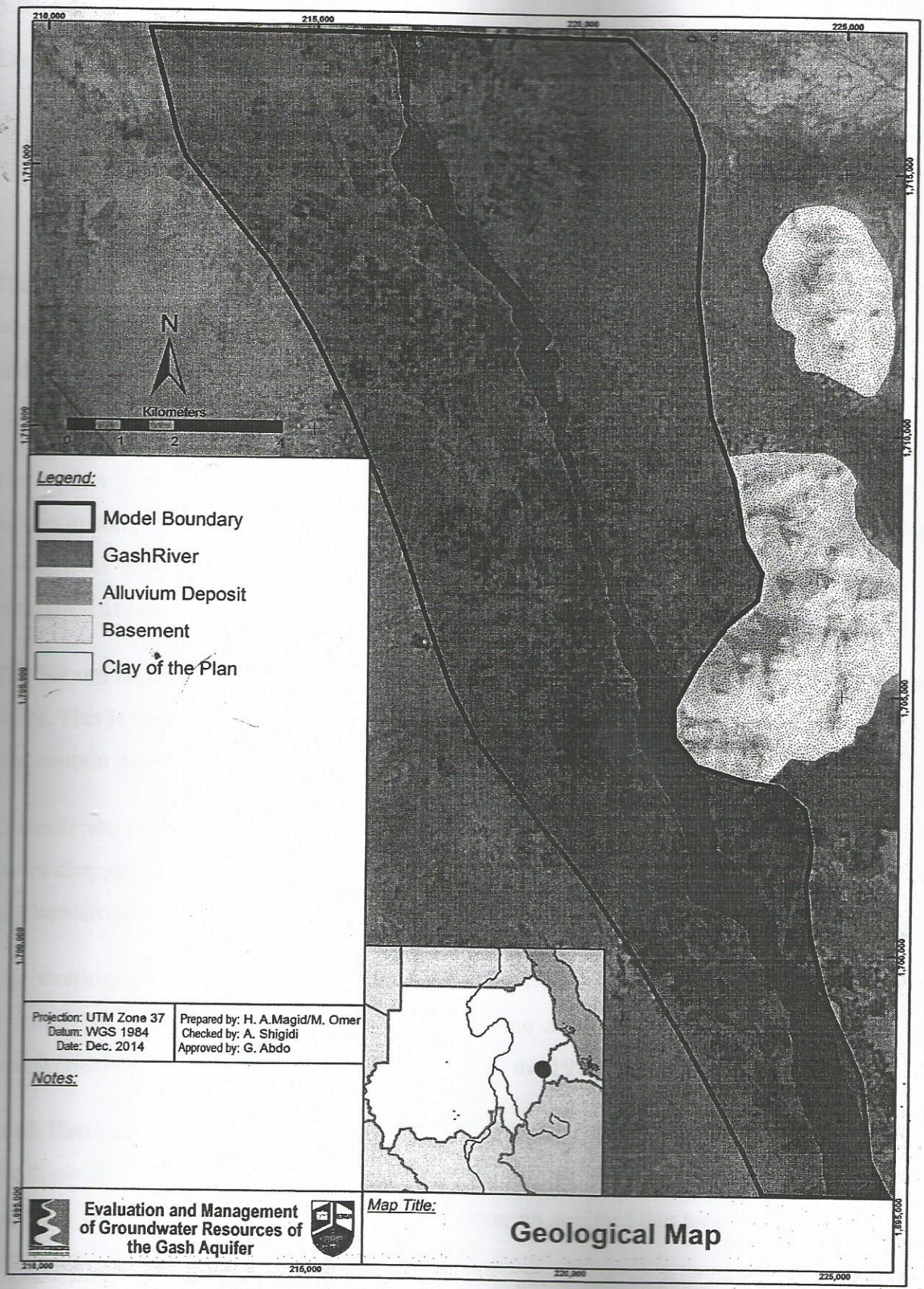


Figure 3-6: Geological Map

3.5 Hydrogeology

The geological setting of the project area identified three main lithostatigraphical units,

- the impervious basement complex
- The less pervious clay of plains
- The very pervious/pervious Gash deposits

The aquifer of the Gash basin is formed of the layers of recent deposits (Gash Deposits), which are mainly fine sandy and gravely deposits and sands. These layers are very previous and permeable, but some less previous layers which are composed of clay and or clayey sands can be found.

The aquifer in some places is overlain by clayey layer of variable thickness that can reach 10 meters in some locations. This top clayey layer increases in thickness when going North West towards the delta. The best aquifer is found along the banks of the Gash River, where it is composed of fine to coarse grained sandy and gravely deposits.

The bottom layer of the aquifer of the Gash basin is formed of impervious gneiss and granitic rocks. This is immediately overlain in some areas with few meters thick weathered rocks layer that contain water but remain of very hydrogeological significance.

Laterally the alluvial deposits pass into moderately less previous deposits as a result of rapid facies changes. Finally they wedge out against the impervious clays of the plain at the eastern and western sides of the aquifer.

The stratiography of the Gash Groundwater Basin was ascertained through the analysis the lithology of a number of wells that penetrates the aquifer, as well as the results of the geophysical investigation of the basin conducted in the 1980 by TNO of the Netherlands.

Gash Basin aquifer is considered as an unconfined aquifer, the less pervious top clayey layers are discontinues and its water storage and transmitting abilities are such that it does not form an upper confining layer, it does constitute however an aquitard that transmits water in limited quantities.

The bottom surface of the aquifer varies from from 450 m.a.s.l. to 519 m.a.s.l. in a North West direction (Figure 3-7). The depth of the aquifer on the other hand varies from 2 m to 56 m (Figure 3-8). A presentation of different transverse and longitudinal profiles of the aquifer

is shown in Figures 3-9 to 3-13. The aquifer boundaries in the east and west directions are delineated by the impervious clays of the plains.

Transmissivity is defined as a product of the average hydraulic conductivity (K) and the saturated thickness of the aquifer (D). Consequently it is the rate of flow under a hydraulic gradient equal to unity through a cross-section of unit width over the whole saturated thickness of the water bearing layer. Values of transmissivity for the Gash aquifer were reported to have been estimated using pumping test data in 1980 by TNO of the Netherlands. The results are reported to be ranging between 2.4 and 2857 m^2/day which translates to a hydraulic conductivity K ranging between 4 and 71 m/day. The effective porosity of the aquifer is estimated to be in the range of 0.2-0.3.

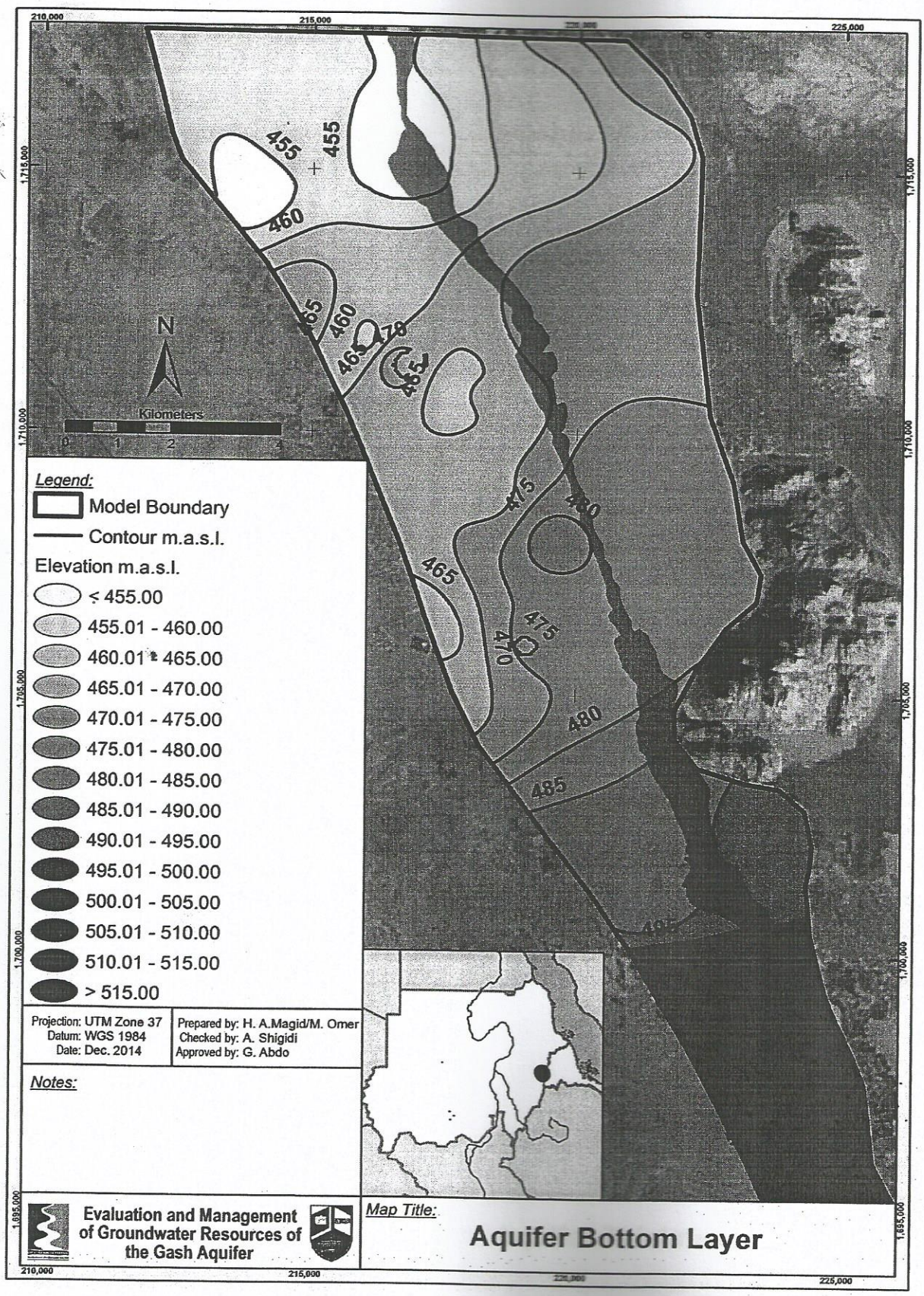


Figure 3-7: Aquifer Bottom Confining Layer

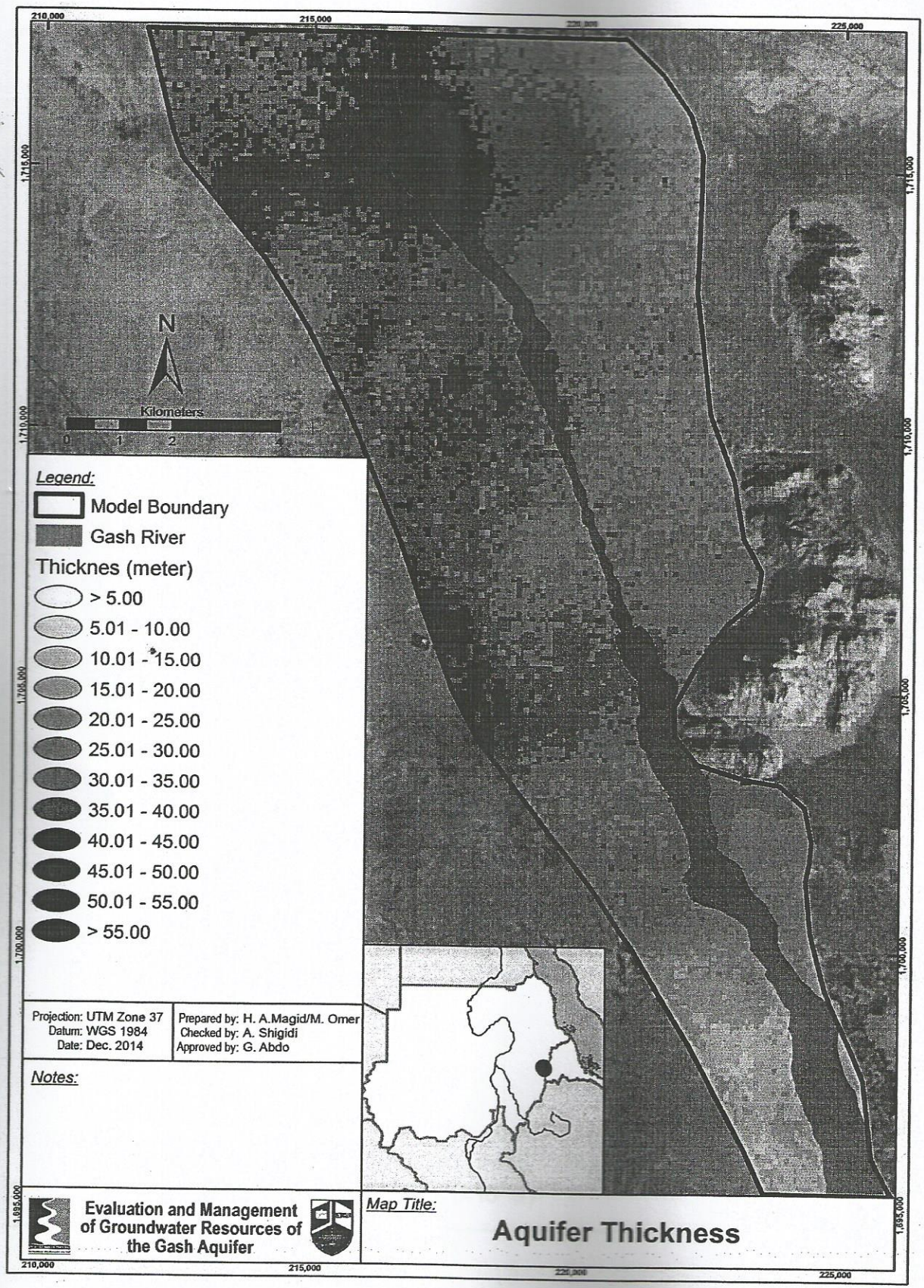


Figure 3-8: Aquifer Thickness

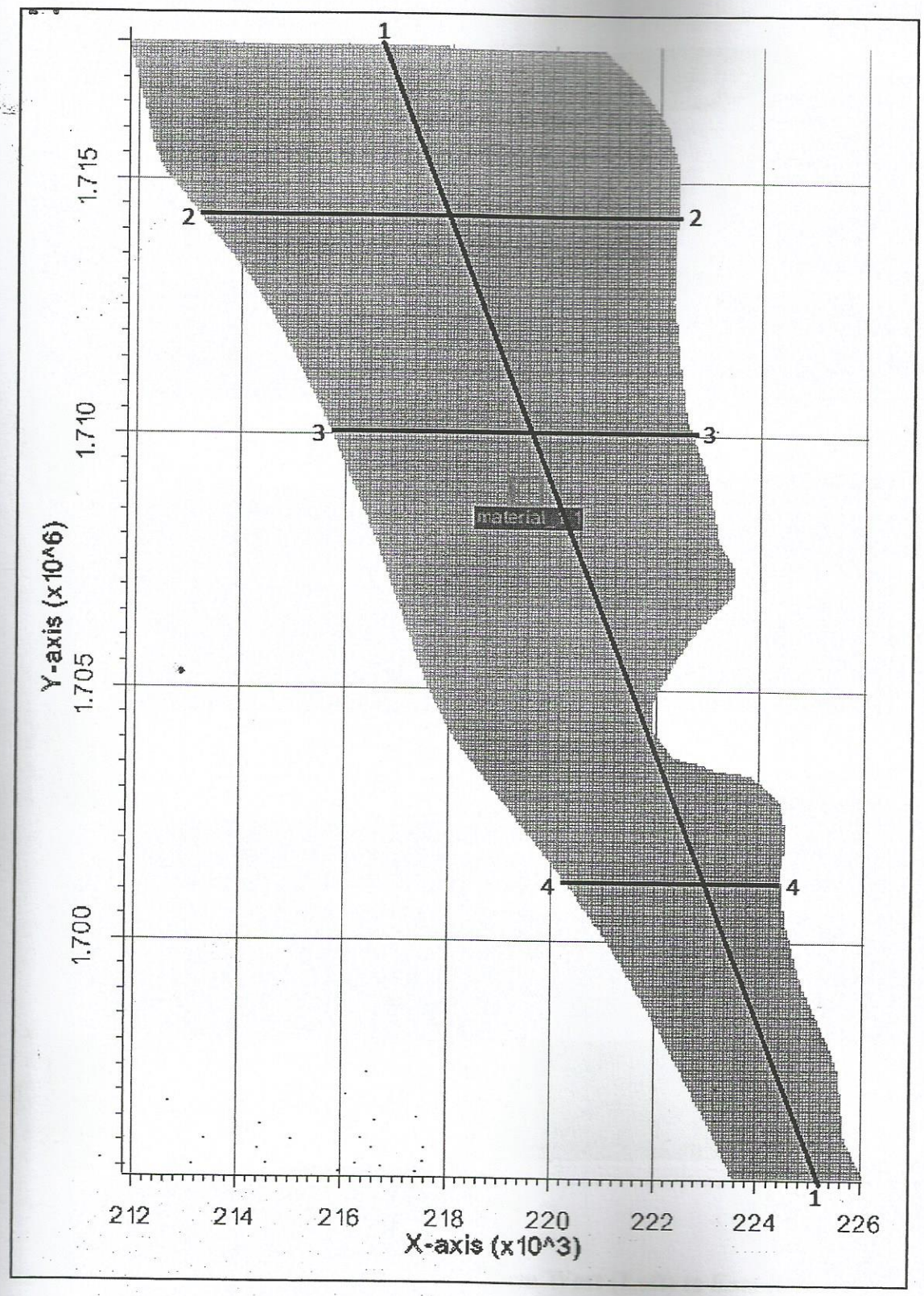


Figure 3-9: Location of the Cross-Sections

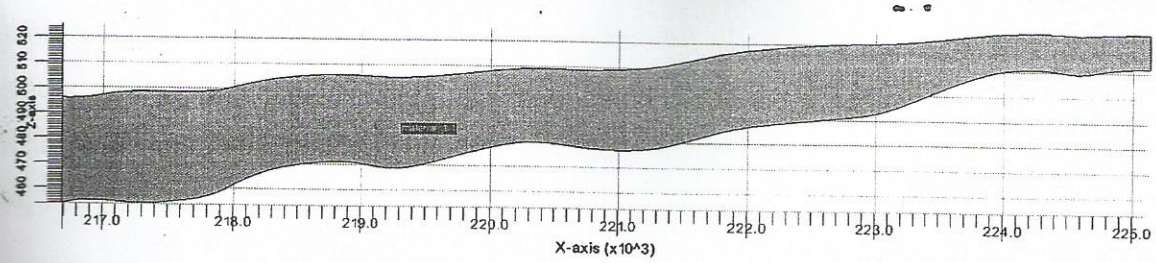


Figure 3-10: Cross-Section 1 (form North (Left) to South (Right))

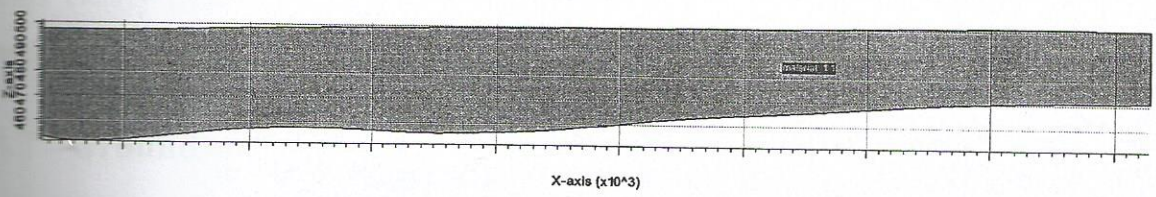


Figure 3-11: Cross-Section 2 (form West (Left) to East (Right))

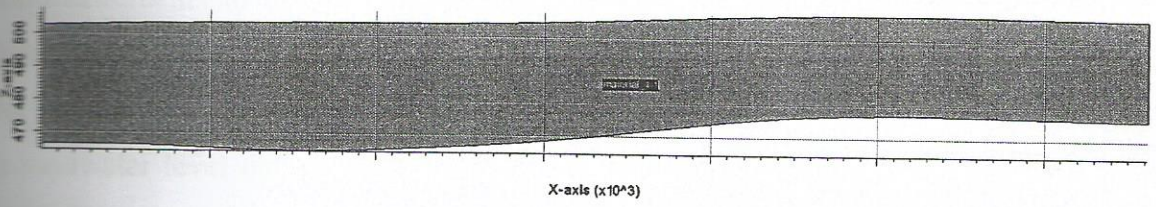


Figure 3-12 : Cross-Section 3 (form West (Left) to East (Right))

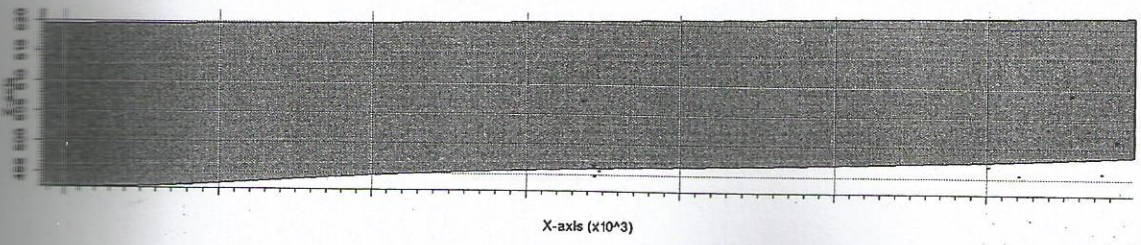


Figure 3-13: Cross-Section 4 (form West (Left) to East (Right))

3.6 Groundwater Flow Pattern

Information about groundwater level data in the Gash Basin was ascertained from the groundwater level maps of 1980 prepared as part of the TNO study as well as the analysis of historic groundwater level data collected during the field visit to the project area. Figures 3-14, 3-15, 3-16 and 3-17 shows water level in 1980, June 1999, October1999 and June 2003.

The groundwater contour lines are consistently and for the most part running parallel to the Gash River, and while there is a northern flow component in the eastern segment of the aquifer the flow in the western part is mainly from river banks and is flowing away from it. This clearly demonstrates that the river is an effluent river that has major impact of the hydrogeological setting of the area.

3.7 Groundwater Level Fluctuations

The hydrograph of the wells in the Gash Basin clearly shows that they exhibit a seasonal fluctuation cycle similar to the flow of the Gash River. Groundwater levels exhibit a steep rise at the beginning of July until the beginning of September which is the period between the commencements to the zenith of the Gash River flow. The groundwater hydrograph then flattens out or declines according to the amount of well abstractions. The difference between the maximum and minimum groundwater level is about 5 meters. The plots of the long term groundwater level data shows that there is depletion trend in the aquifer between 1999 and 2012 (Well No. 48), where the peak groundwater level is annually regressing (Figure 3-18). Figure 3-19 show the monitoring wells in the area and the location of well No. 48.

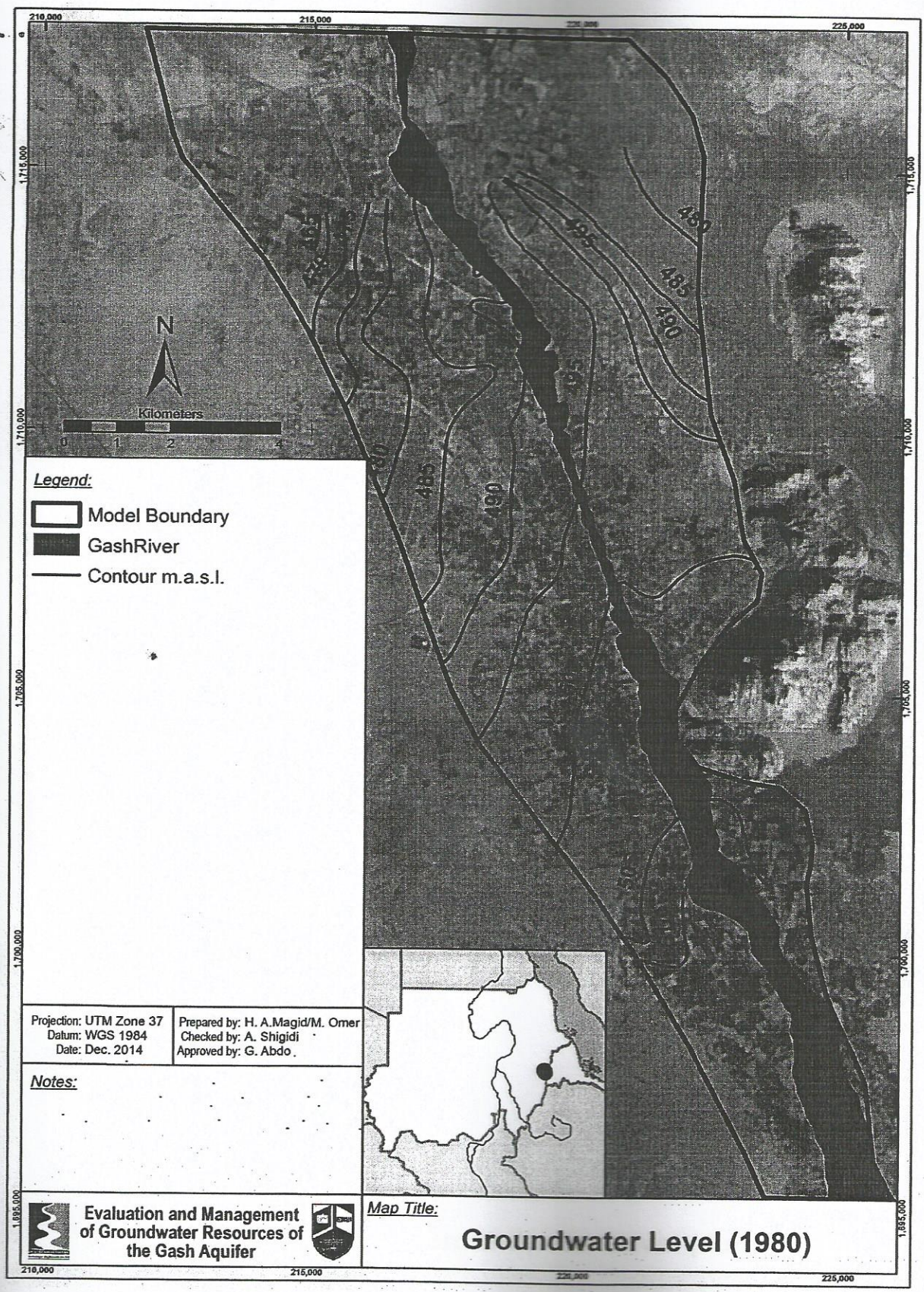


Figure 3-14: Groundwater Level Map for Yaer 1980

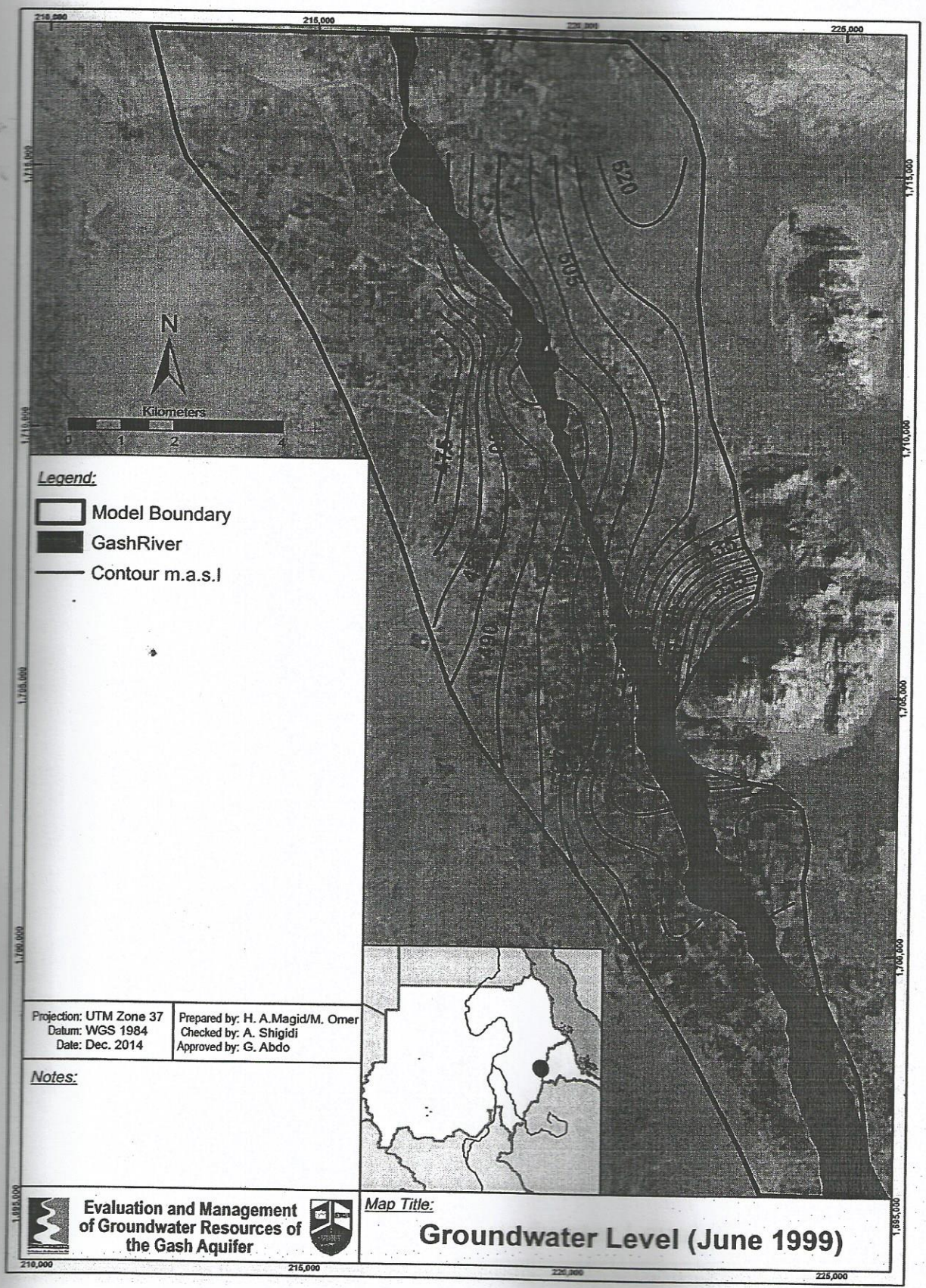


Figure 3-15: Groundwater Level Map for June 1999

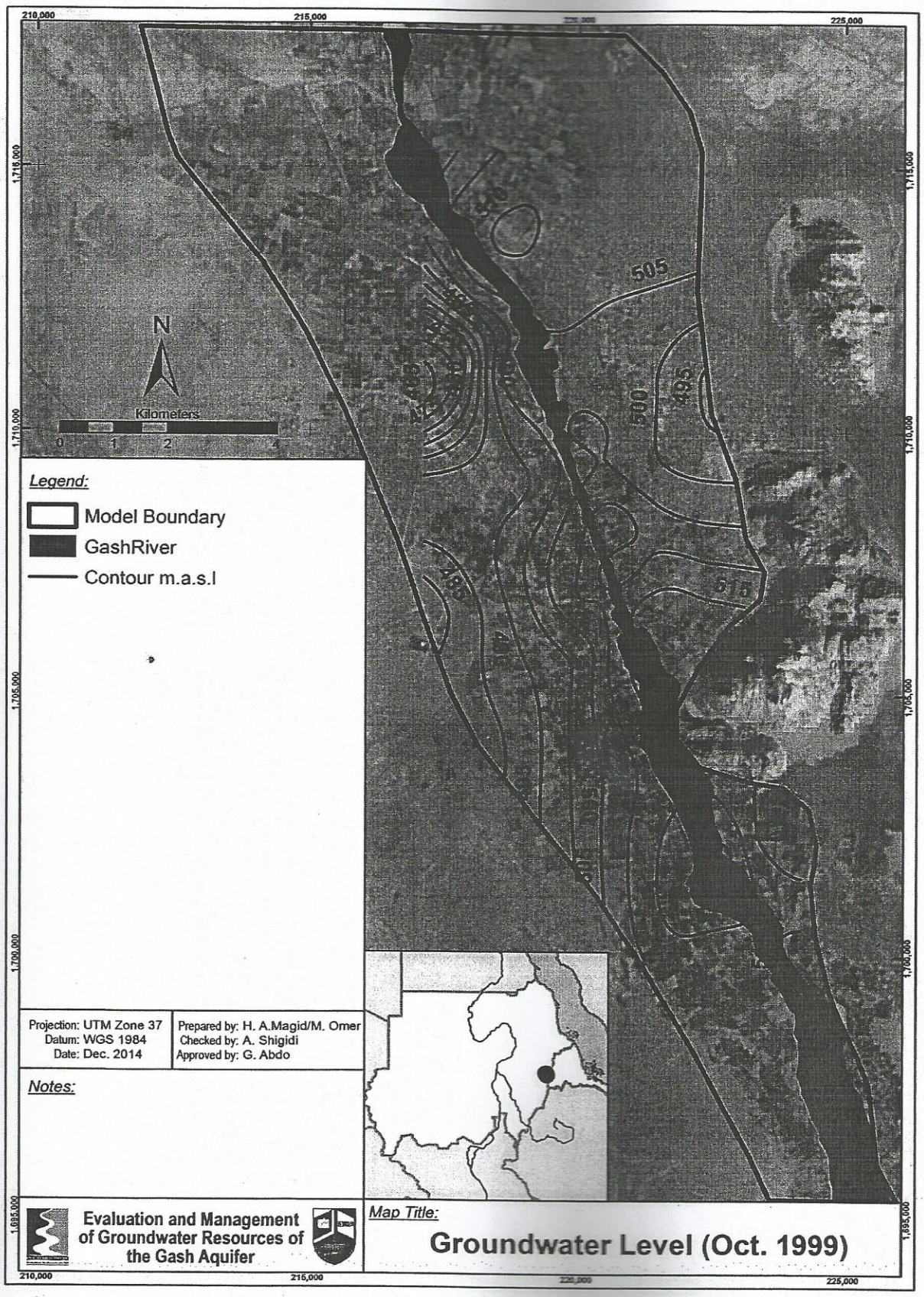


Figure 3-16: Groundwater Level Map for Oct. 1999

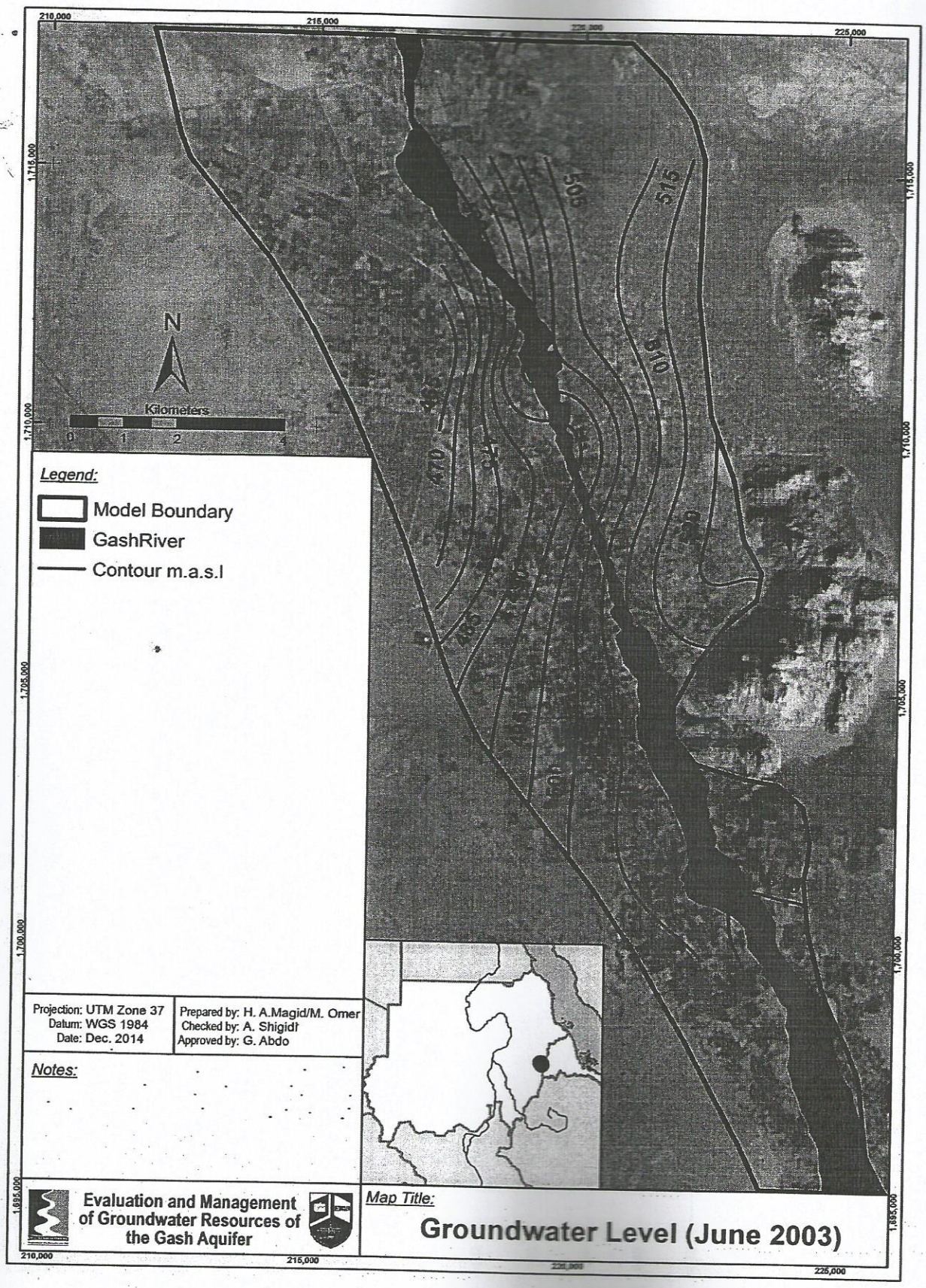


Figure 3-17: Groundwater Level Map for June 2003

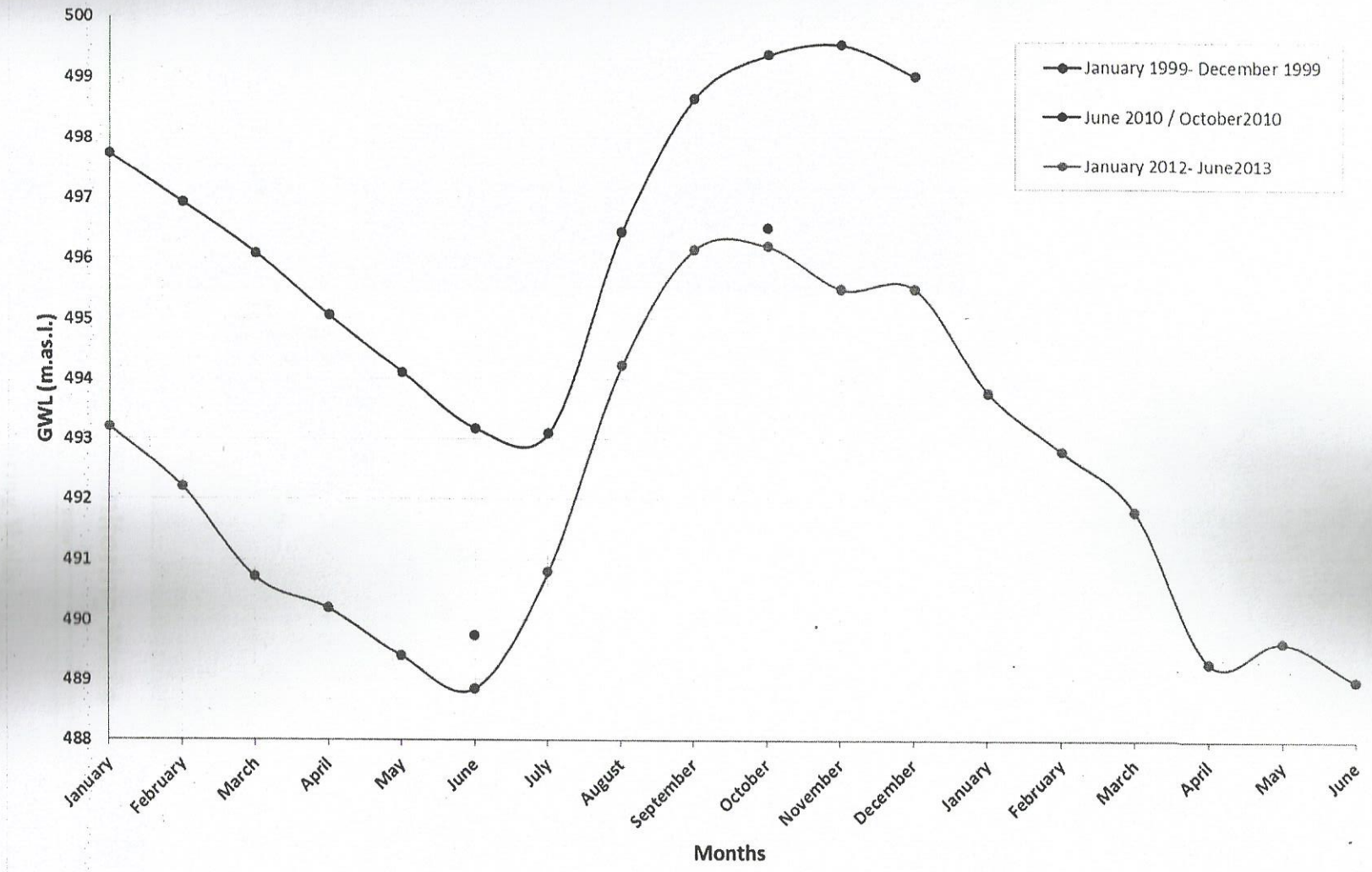


Figure 3-18: Temporal Fluctuation of the Groundwater Level in Well No. 48

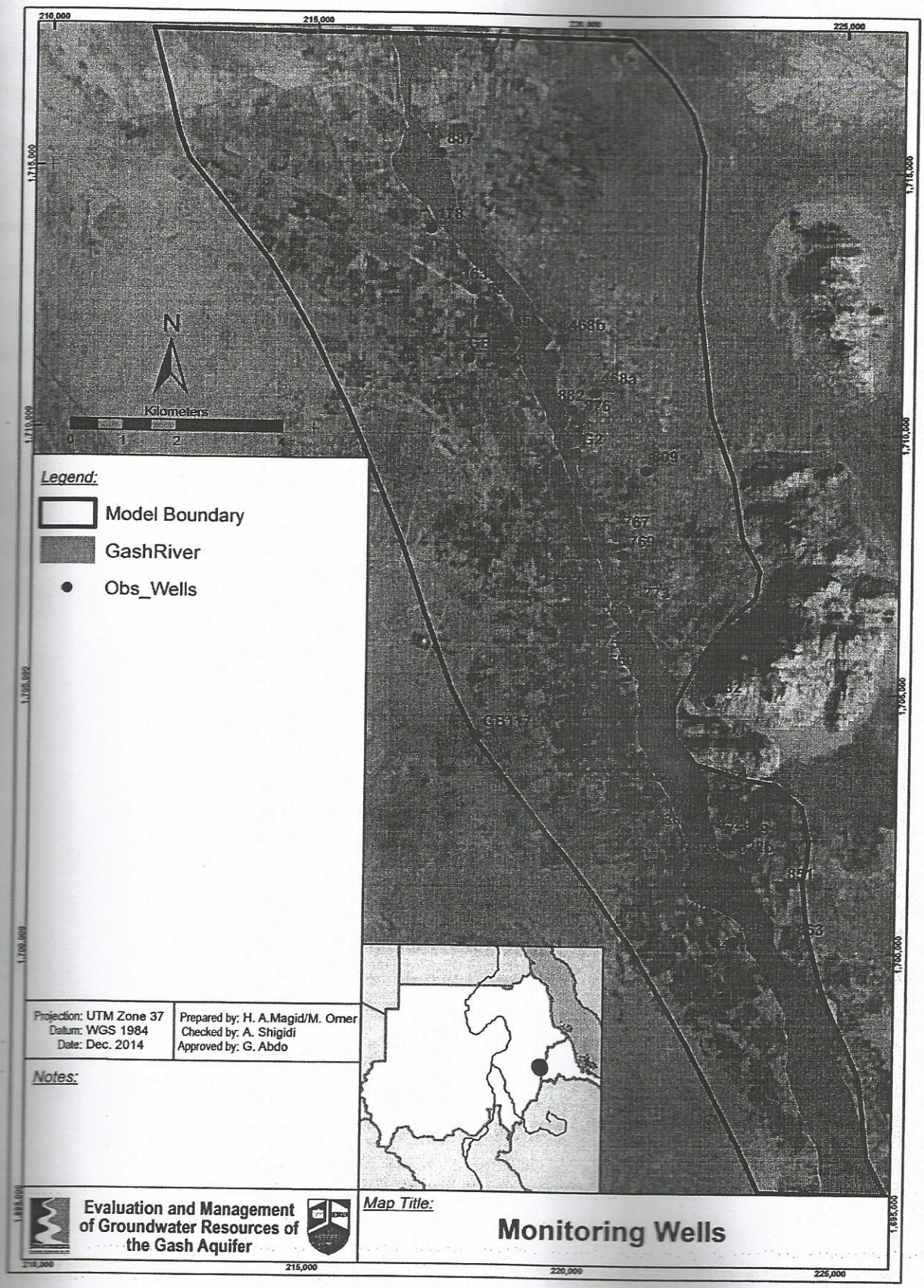


Figure 3-19: Monitoring Wells

Gash River Flows and Water Levels

River is monitored by three stations The Bridge and Gera and Salam Alikum (Figure 3-
The river data collected comprises the Gash daily water levels in an hourly time series
the period approximately from the end of June till the beginning of October for the years
to 2014. The average daily levels for each year were obtained and the ten day means
dering that this is the form of data which should be inserted into the model. Taking the
2010 as an example, the following results are obtained as demonstrated by the graphs in
es 3-21 to 3-24. Ten day stage data for the Gash River reach within the model boundary
e years 2004 and 2013 is shown in Figures 3-25 and 3-26. The remaining stage data for
riod from 2005 to 2012 is shown in Annex 2.

be clearly seen that the peak water.level. occurs in August and it declines to it's lowest
s in the beginning of July and the beginning of October. According to the graph there is
variance in the water.level throughout the measuring period as it reaches a maximum
of 1.14 for Bridge and 1.78 for Gera which are both less than 2m.

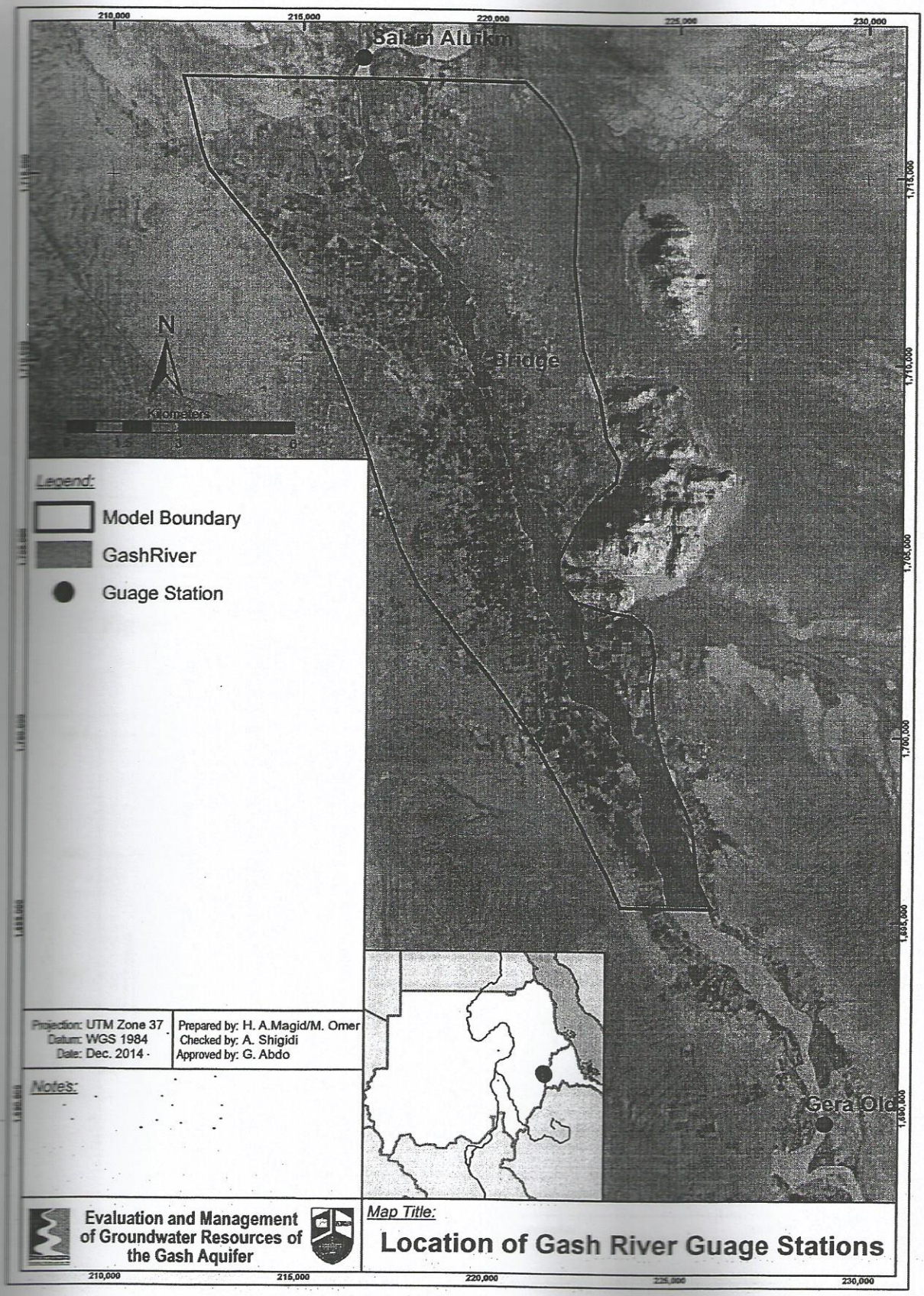


Figure 3-20: Location of River Gash Gauge Stations

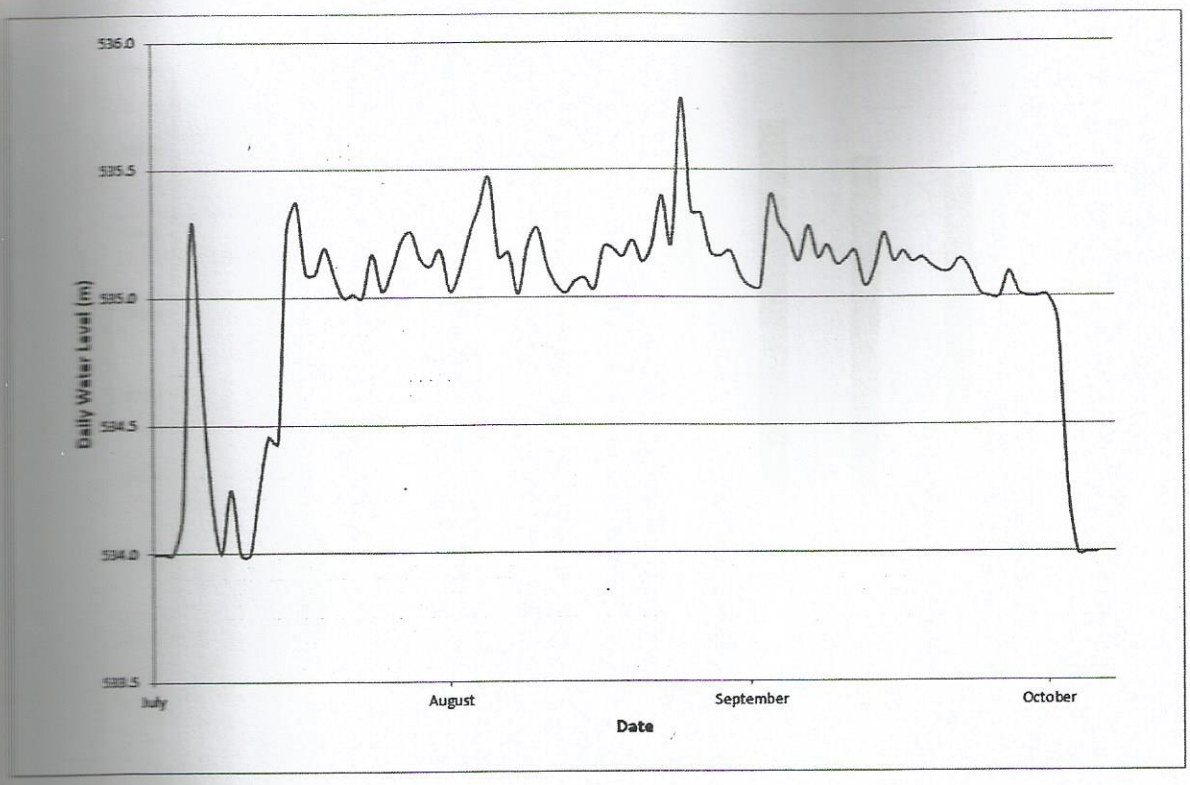


Figure 3-21: Daily Water Levels for Gera Station for the Year 2010

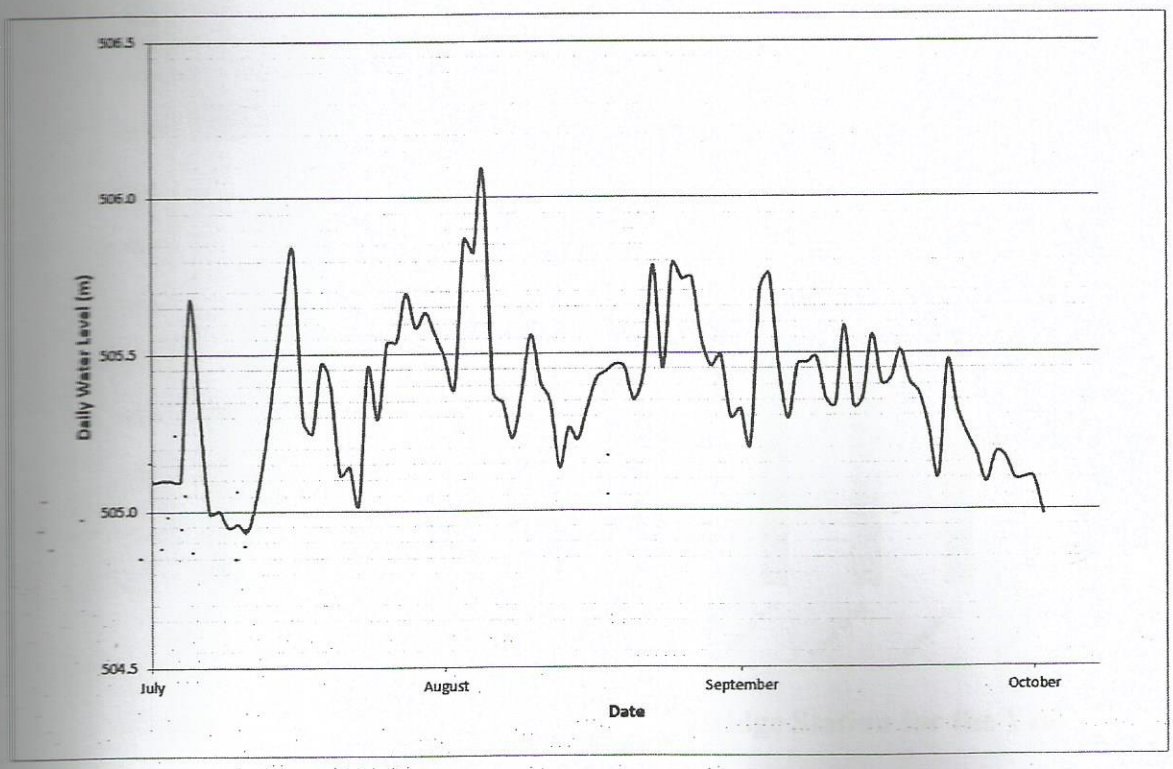


Figure 3-22: Daily Water Levels for Bridge Station for the Year 2010

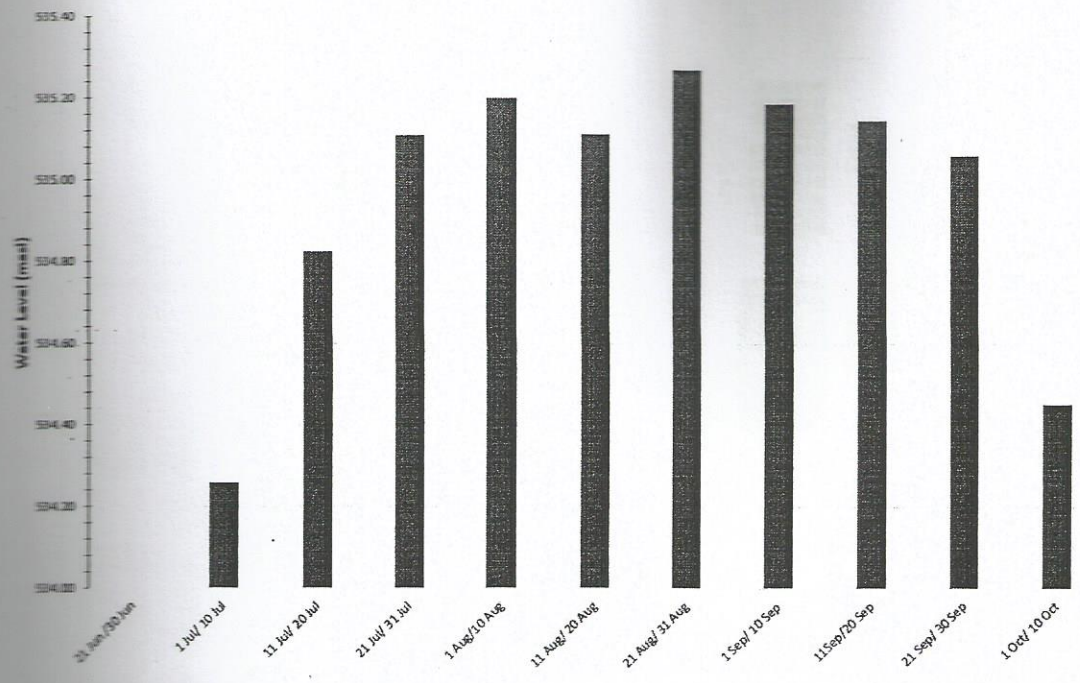


Figure 3-23: Ten days Water Levels for Gera Station for the Year 2010

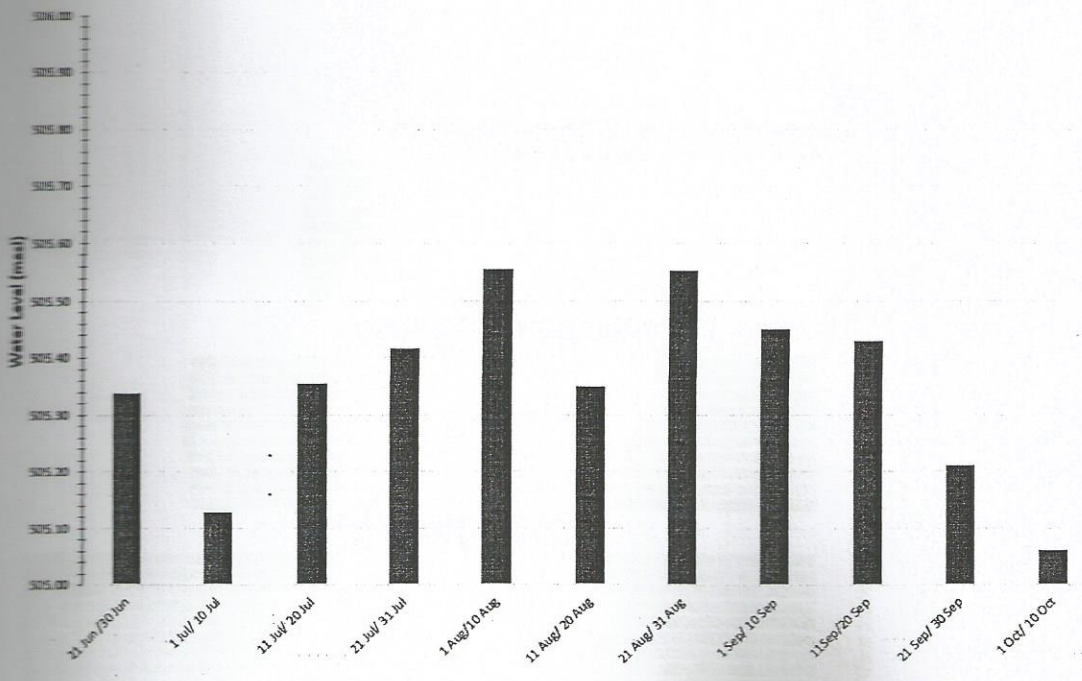


Figure 3-24: Ten days Water Levels for Bridge Station for the Year 2010

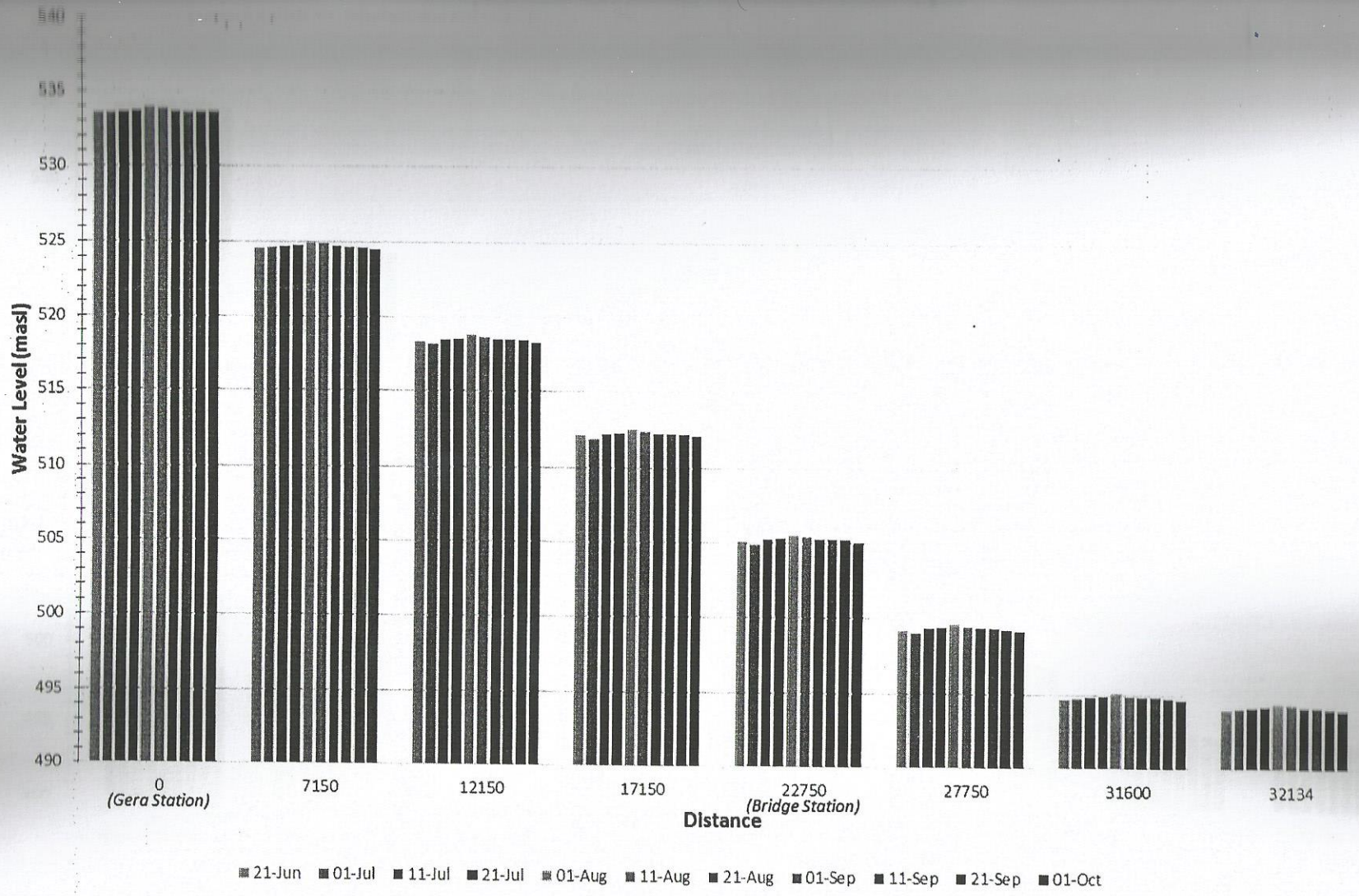


Figure 3-25: Ten days Water Levels for Gash River for 2004

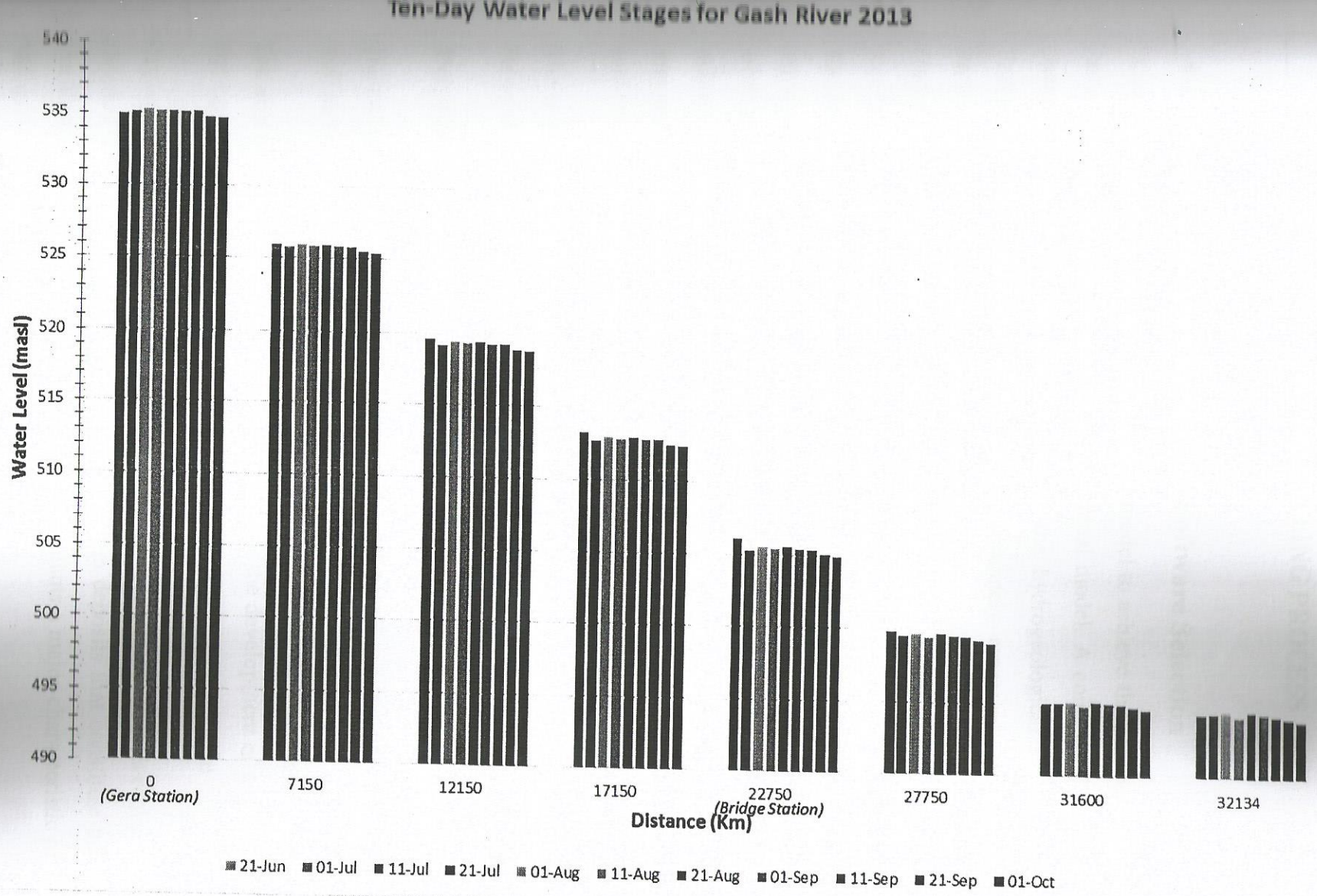


Figure 3-26: Ten days Water Levels for Gash River 2013

4 MODELLING PROCESS

4.1 Model Conceptualization and Software Selection

Construction of a successful mathematical model to achieve the proposed objectives requires as a first step the development of a conceptual model. A conceptual model is a simplified representation of the essential features of the hydrogeological system and its hydraulic behaviour. The conceptual model should accurately represent the boundary conditions, hydrogeologic parameters, groundwater flow directions, layering system, inflows from different sources; outflows, and the seasonal variations of inflows and outflows. The development of a conceptual model for the Gash Basin is one of the most important aspects of the present groundwater modelling study. Usually In developing a conceptual model for an aquifer, several simplifying assumptions needs to be adopted. It is recognized however that oversimplification may lead to a model that lacks the required ability to model the system and achieve the objectives of the study, while under simplification may result in a costly model that requires substantial amount of input data. Data availability also plays a pivotal role in the undertaking the assumptions required to develop the conceptual model.

The implementation of a groundwater model most appropriate for the Gash aquifer involves the consideration of a number of factors, namely:

The physical characteristics of the study area (both surface and hydro-geological)

The utilization of all available data, including geological and hydro-geological information as well as historic and recent records of groundwater levels.

The aim of the investigation, which is surmised as the development of a mathematical model that can be used for groundwater management in the Gash Aquifer basin

Geological data establishes that the Gash Basin is underlain by igneous rocks. This basement complex acts as a confining layer for the alluvium deposits that constitute the Gash Basin. The Basin is bounded in its sides by clays of the plains a major characteristic of which is the negligible hydraulic conductivity.

Based on geological and physical characteristics of the study region, the following factors and assumptions will be adopted to determine the layout and internal structure of the groundwater model:

The Gash aquifer is comprised of one unconfined aquifer underlined by basement complex

The Gash River is the primary source of recharge to the aquifer as the groundwater level in the vicinity of the recharge area varies seasonally with changes in the river water levels.

Rainfall also contributes to aquifer recharge

The aquifer is bounded by the clay of the plain in its Western and Eastern sides and therefore they can be modelled as no flow boundary conditions. Head Dependent Flux (Cauchy) type boundary condition will be used to model the interaction between the aquifer and the Gash River. The Southern and Northern boundaries are modelled as no flow boundaries.

The depth of the aquifers in the study varies according to the compiled lithological data available

Figure 4-1 shows a three dimensional view of the conceptual model of the aquifer. Cross sections at different locations have already been shown in Figures 3-9 to 3-13.

The software package GMS was applied to develop the numerical model of the Gash basin aquifer. GMS is a pre-processor and postprocessor of the modular three-dimensional finite difference groundwater model "MODFLOW" which is developed and published by the U.S. Geological Survey. It is well-known and powerful software that can simulate all features that occur within the aquifer such as river-aquifer interaction.

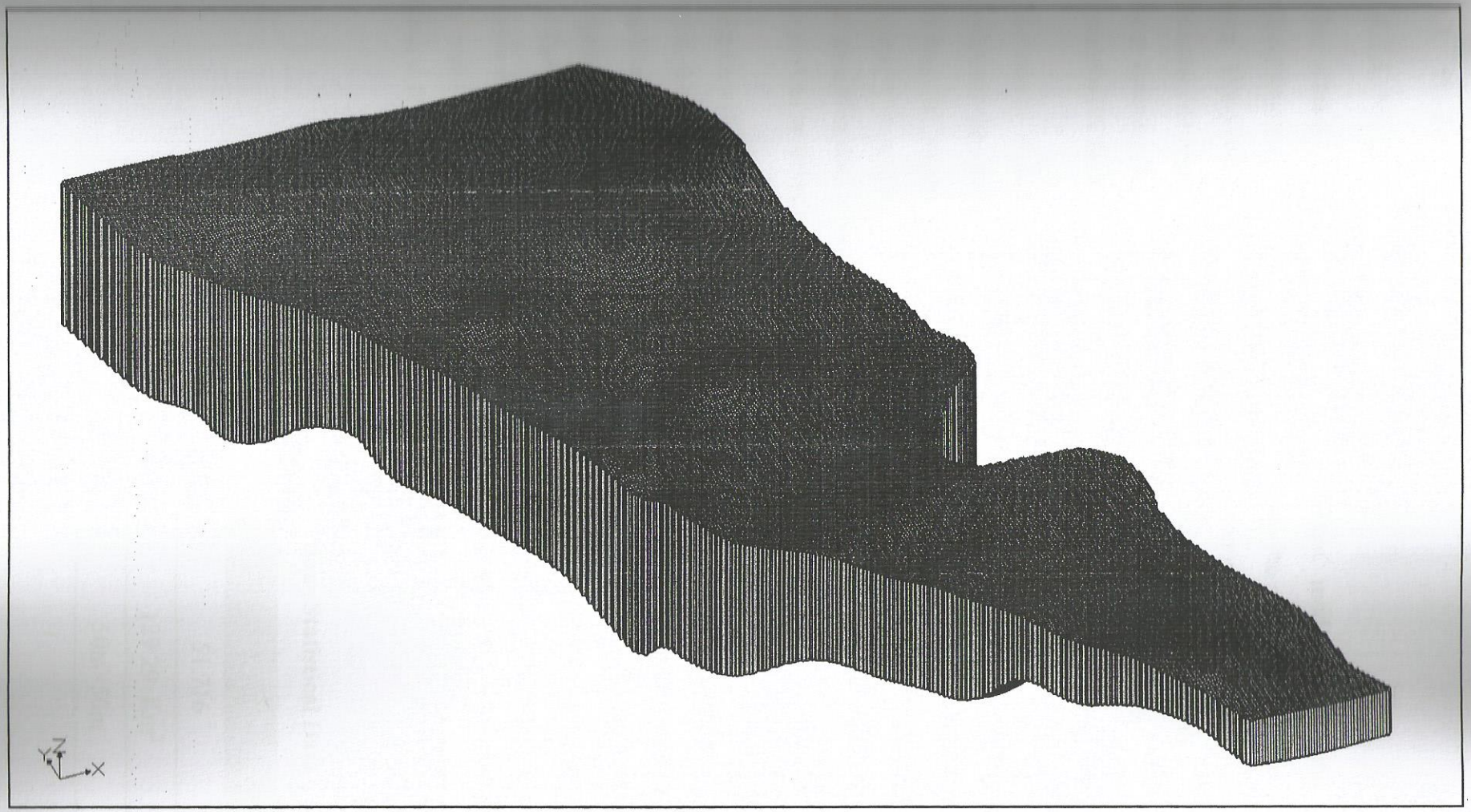


Figure 4-1: Three Dimensional view of the Conceptual Model

4.2 Model Construction

4.2.1. Spatial Discretization

The reliability and accuracy of a groundwater model, as a mathematical-numerical approximation of reality, depends significantly on the appropriate discretization of the model area. This must take into account the specific topographic, geological and hydrogeological boundary of conditions of the study area. In addition, the layout of the finite difference mesh must consider both the characteristics of the project area and the expected interventions in groundwater flow due to variations of the boundary conditions.

The model includes a very large number of rectangular cells. The groundwater model computes the resulting groundwater level at the center of each cell. The surface created by joining the center of each element describes the three-dimensional orientation of the groundwater surface in the study area and enables a fully three-dimensional interpretation of the available data. This in turn allows the analysis of the existing depth to groundwater based on present as well as future groundwater conditions.

Regular cells of size 50m × 50m was used in this study. The errors caused by modelling the three-dimensional water surface with cells of such a size are negligible. The aquifer was modeled as a single unconfined heterogeneous and isotropic layer with varying thickness depending on the available lithological data. The statistical data of the discretization is listed in Table 4-1. The finite difference mesh of the model is shown in Figure 4-2, in which the active cells, inactive cells and the river cells are indicated as shown in the Figure 4-2. It is to be noted that the finite difference mesh is not clearly seen due to the small size of the grid (50m x 50m).

Table 4-1: Spatial Discretization- Statistical Data

Parameter	Data
Number of Cells	51.716
Model Area	129.29 Km^2
Element Size	50m×50m

4.2.2. Aquifer Geometry and Boundary Conditions

Areas of the aquifer that are bounded by the clay of the plain are clearly defined as the end of aquifer and were modeled as no flow boundary conditions. The Northern and Southern perimeter was adopted as no flow boundaries. The Gash River was modeled as river boundary condition. The average monthly or 10 day gauge levels in the three gauging stations within the river reach were used to estimate the levels at different points within the two stations by linear interpolation. As such the constant hydraulic head boundary for every 50 m segment of the river was computed for every 10 days of the month.

4.2.3. Aquifer Stresses

The Gash Basin hydrogeology is dominated by the Gash River seasonal flows. It had been observed that the groundwater within the Basin are replenished towards the end of the Gash Flow seasons and their levels dwindle in the dry season before the beginning of the cycle of the Gash flow in May-June. The Gash River was modelled using the River Package in the GMS software. The cross sections of the river at the three gauging stages of Gera, Bridge and Salam Alikum were used to obtain the river bed elevations at the three locations. These values were subsequently used to interpolate the values of the River Bed elevation within the bounds of the Gash River throughout the whole model domain. The ten day average river stage was also calculated for each of the three stations and the ten day river stage was subsequently calculated at all the cells that constitute the geometry of the River for each year between 2004 and 2014. The conductance between the River and the Aquifer was assigned a constant initial value of 500 m^2/day which was subject to change within the planned process of model calibration.

While the River provided for all practical purposes all the recharge to the Gash Basin, irrigation activities consumed about 90% of it utilized waters (about 100 million m^3/year). The irrigated areas within the basin boundary were identified from satellite imagery and were estimated to have an area of about 20,000 feddan. With an average groundwater abstraction of 5100 m^3/feddan the annual abstraction for irrigation was estimated to be about 3.3 mm/day between 2004 and 2010. Abstraction by Kassala City water supply stations accounted for the remaining groundwater development. Two main stations were identified as operational between 2004 and 2010, namely Kassala Bridge water supply station and West al-Gash water supply station. with abstractions rates of 11,000 m^3/day and 9,000m^3/day respectively.

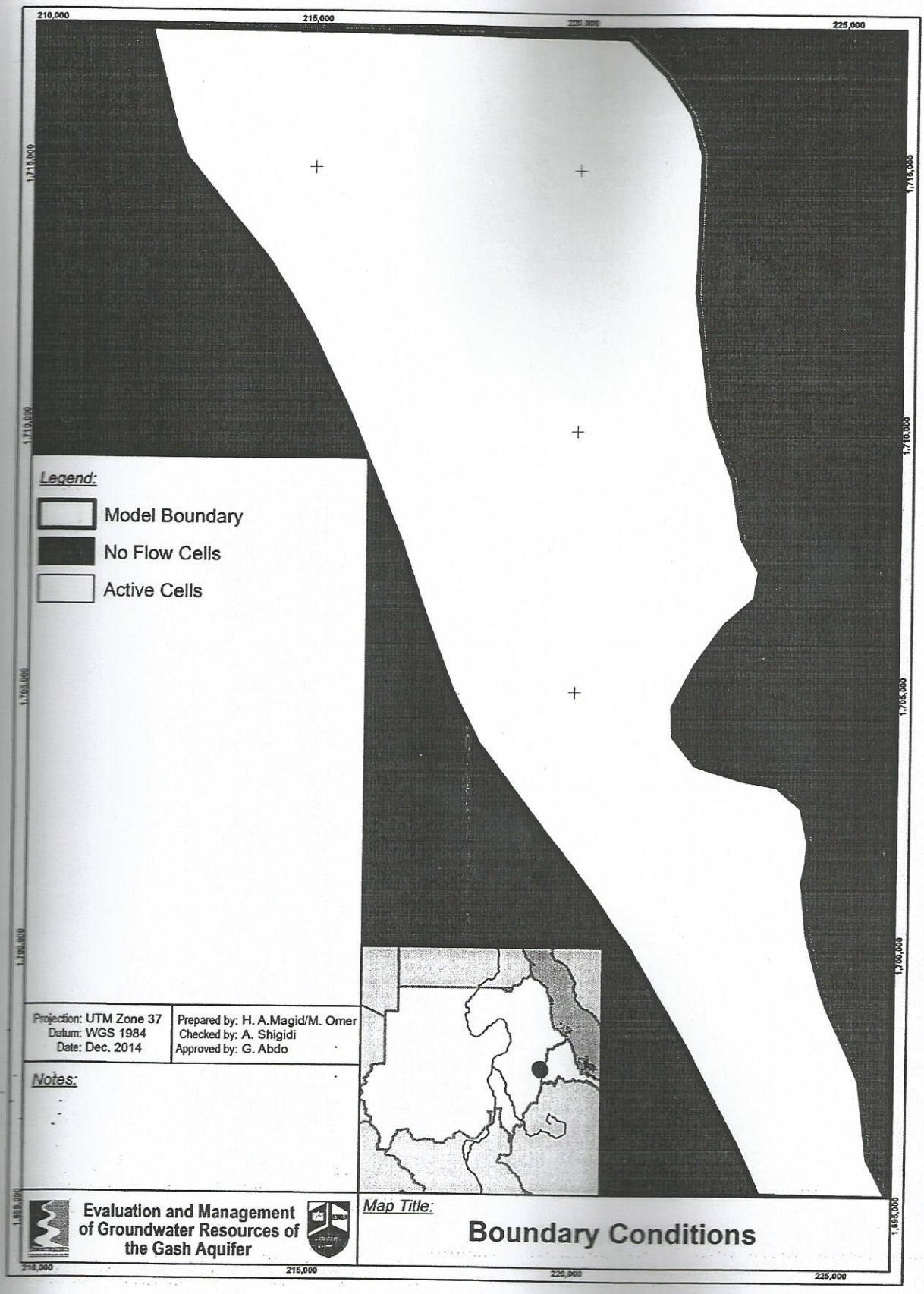


Figure 4-2: Boundary Conditions

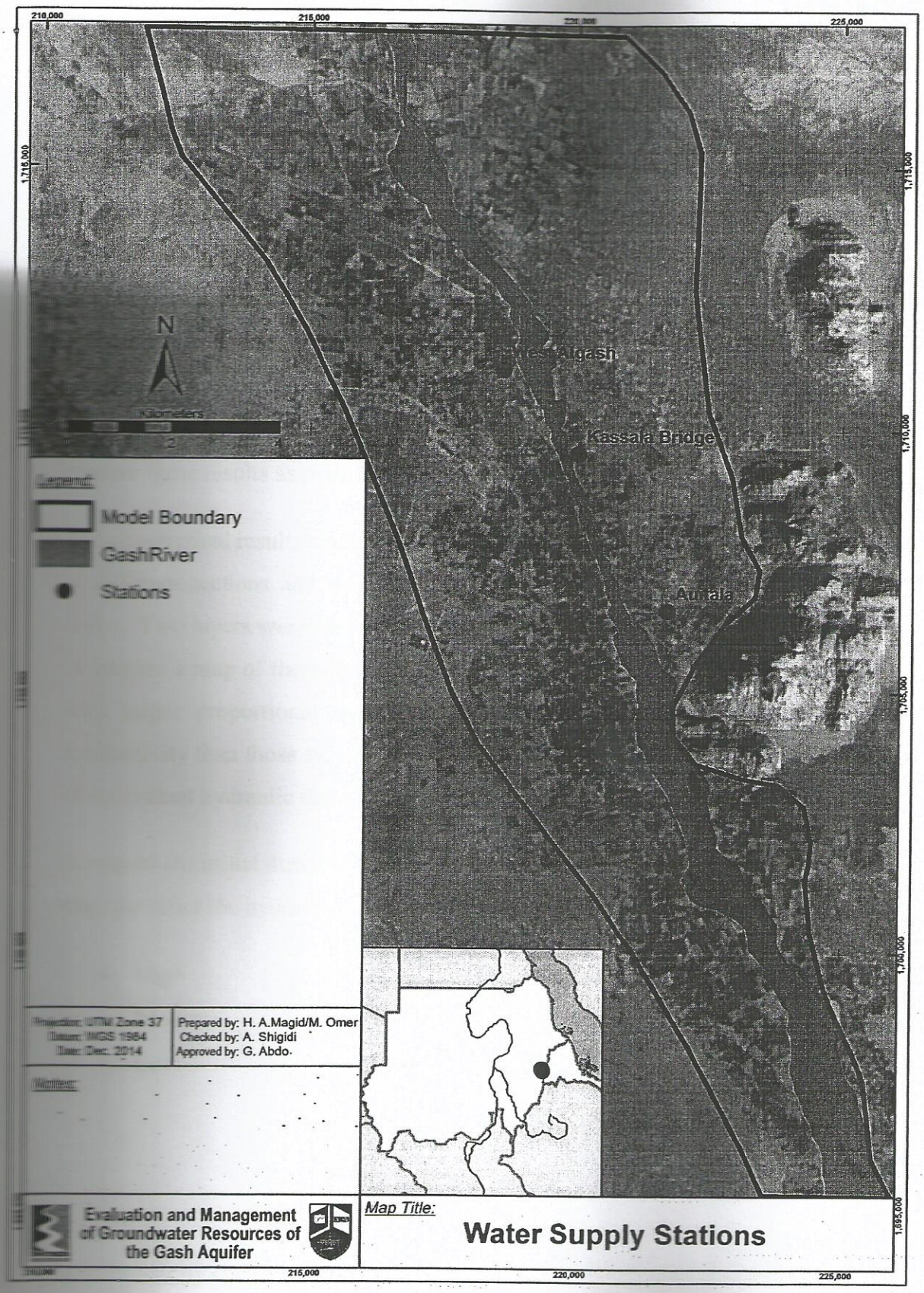


Figure 4-3: Location of Water Supply Stations

4.2.4. Hydraulic Properties

The estimation of the hydraulic properties is an indispensable element in the characterization of any aquifer. One of the first attempts to estimate the hydraulic properties of the Gash Basin was conducted by TNO in 1982 by using borehole pumping tests and recovery data.

The study reported transmissivty values ranging between 2.4 m^2/day to 2857 m^2/day which translates to hydraulic conductivity "K" ranging between 4 and 71 m/day and specific yield values ranging between 0.0019 and 0.015. The study was however deficient as it used low pumping capacity (less than 30 m^3/hr) which is most probably insufficient to induce aquifer excitation. This factor combined with the fact that during in the conducted pumping tests the distance between the pumping well and the observation wells were less than ten meters apart renders these results as marginally dependable.

The geophysical results study conducted for the study area delineated that depth of the aquifer at different sections and identified the properties and thickness of the different underlying layers. Two layers were identified, alluvium deposit and aquitard. This information was used to prepare a map of the relative hydraulic conductivity within the model area where the cells with larger proportional depth of aquitard were assigned a lower equivalent hydraulic conductivity than those which comprised a lesser percentage of aquitard by using the concept of equivalent hydraulic conductivity

A map of the initial distribution of hydraulic property values was developed (Figure 4-4). The map classifies the hydraulic conductivity into five categories:

- High
- Medium
- Low

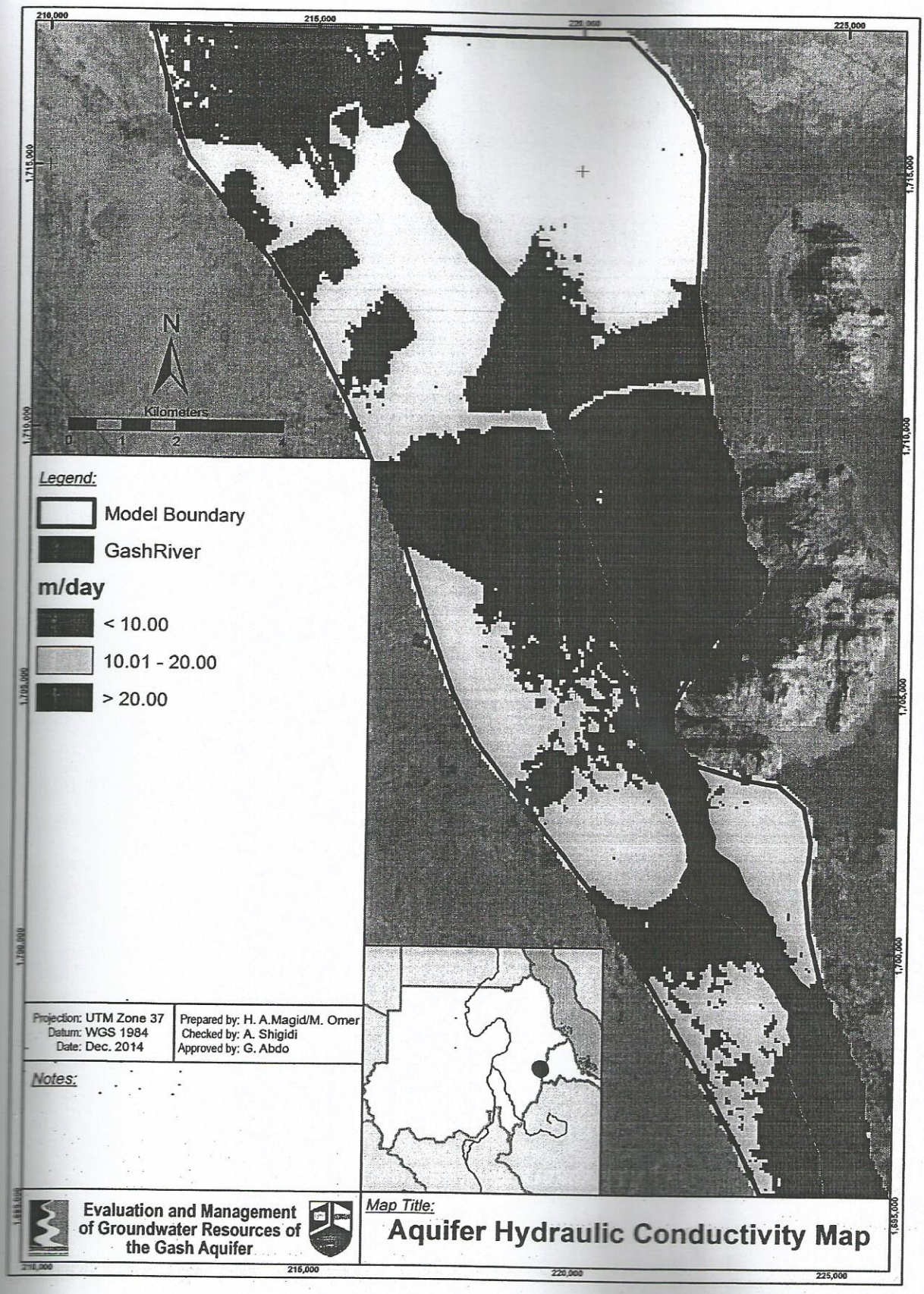


Figure 4-4: Aquifer Hydraulic Conductivity Map

The results of the calibration process confirm that the groundwater model is able to reliably simulate the groundwater flow and levels in the study area under transient conditions within acceptable limits.

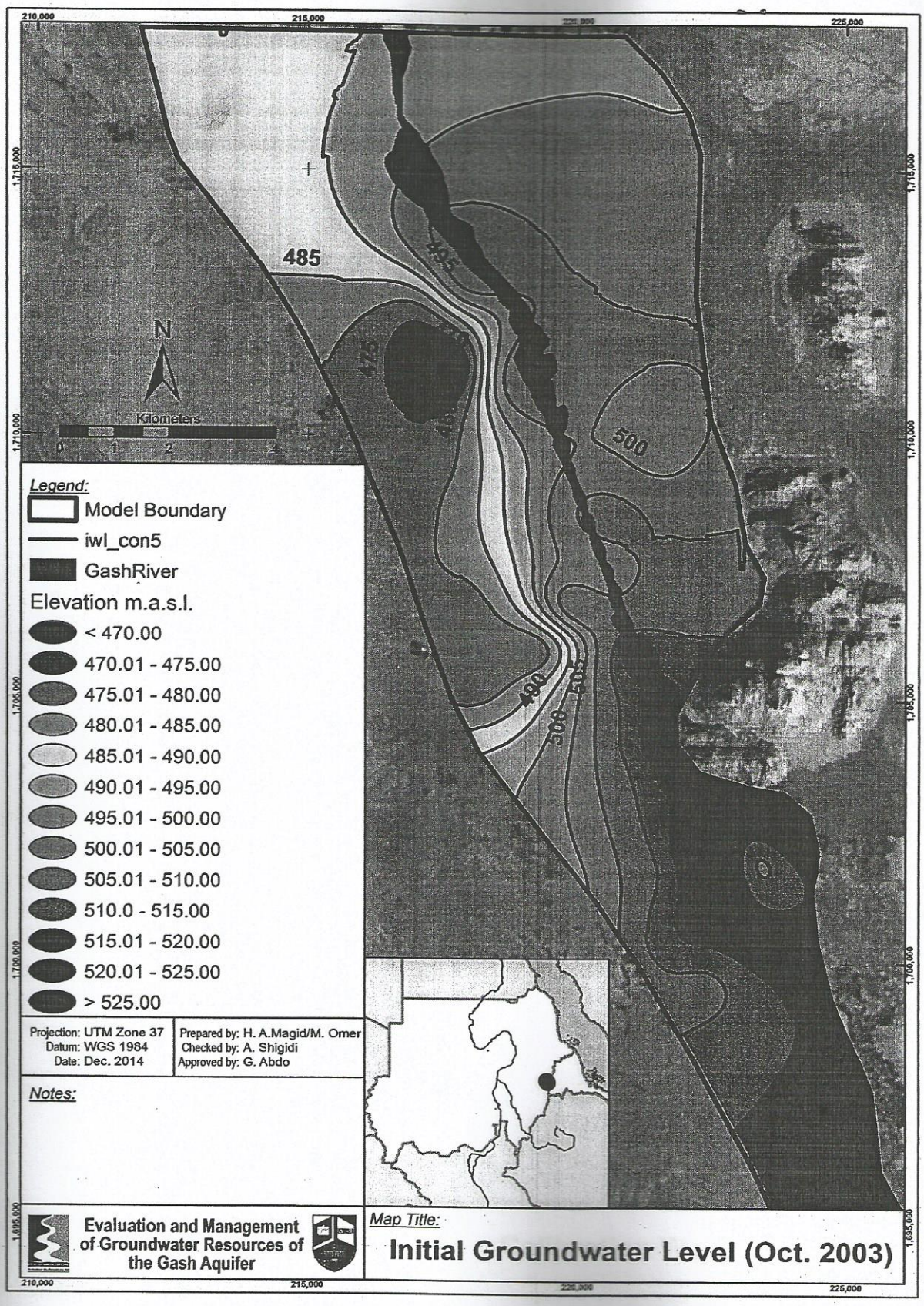


Figure 4-5: Initial Groundwater Level Map for October 2003

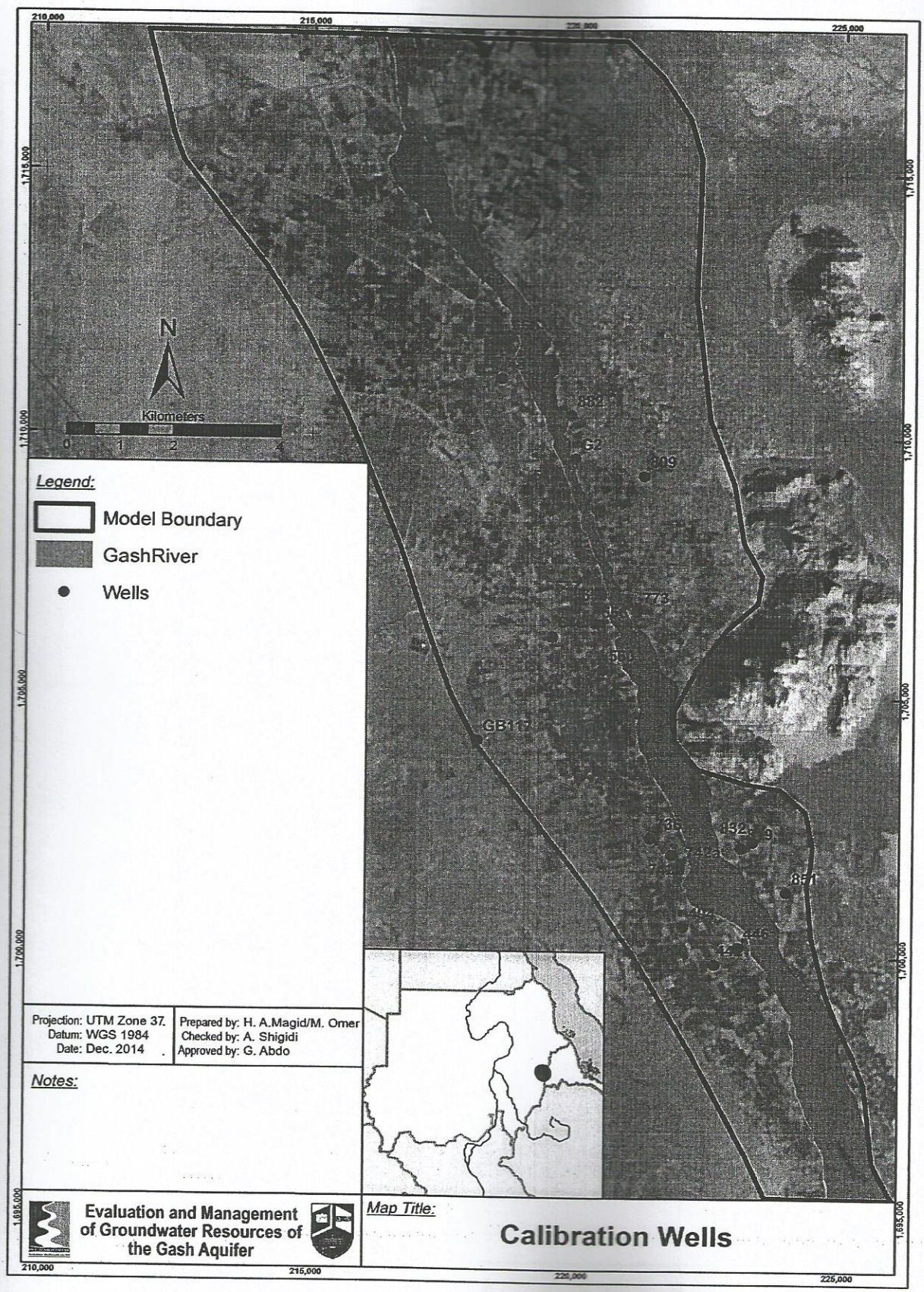


Figure 4-6: Distribution of Calibration Wells

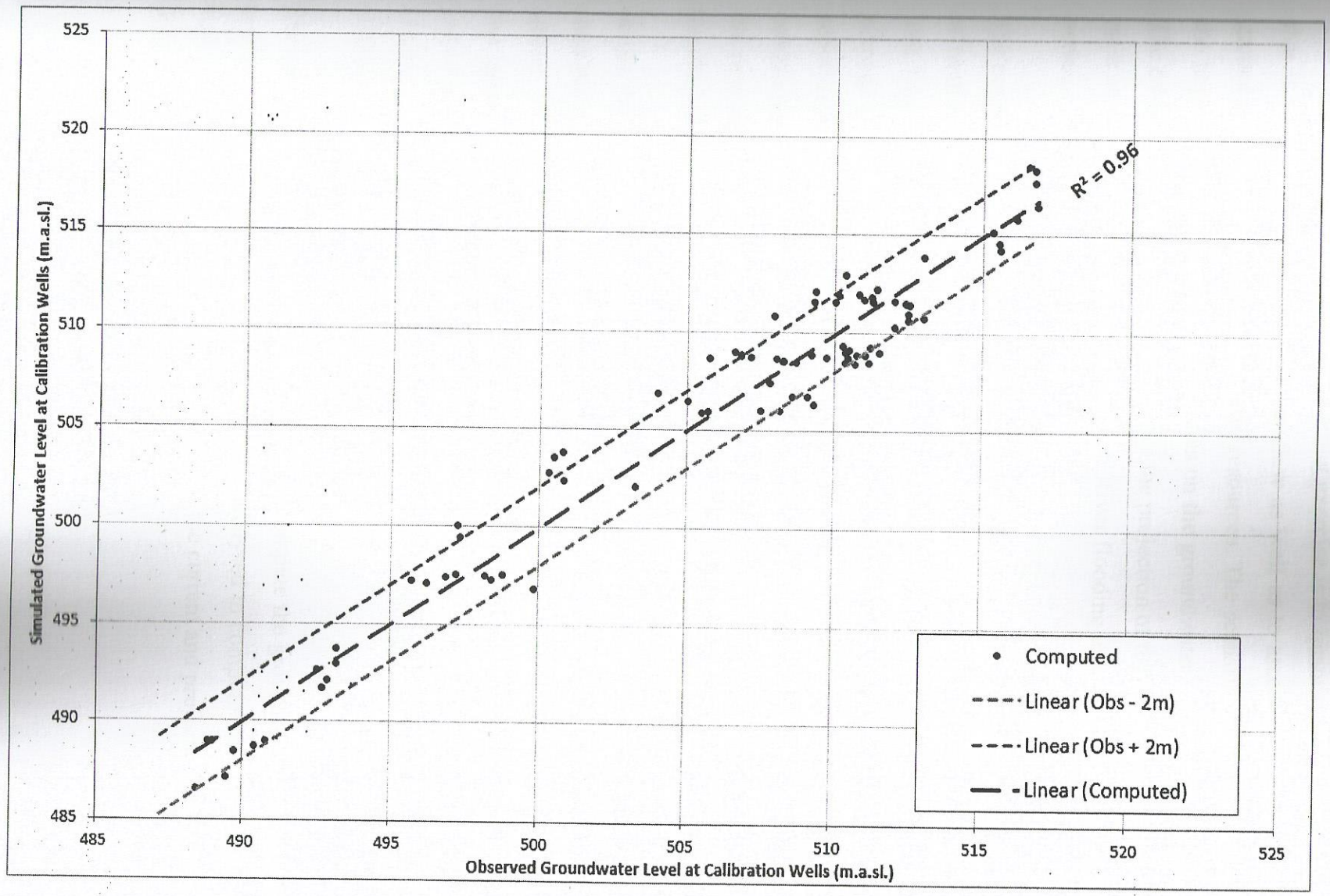


Figure 4-7: Scatter Diagram of Model Simulated Vs Observed Groundwater Levels

4.4 Scenario Development

The objective of the Gash Basin modeling exercise is to quantify the recharge to the aquifer that is emanating from the Gash river flow as well as to ascertain the long term impact of groundwater development on the basin resources. The scenario that is investigated includes the impact of the project abstraction rates on the groundwater level within the next 20 years. The development of this scenario requires the projection of the future groundwater abstraction rates as well as the forecasting of the Gash River flooding levels for each year of the scenario period.

The majority of the groundwater abstraction takes place within the Bash Basin for the purpose of horticultural development. While this development witnessed limited growth during the past five years as recorded by the state ministry of agriculture, limited annual growth was allowed (5%) for five years (2015-2020) after which the abstraction rates for agricultural activities is assumed to remain constant. Pumping for the satisfaction of the domestic water consumption needs was projected to increase by 55% by 2014 due to the commissioning of the new water yard and to increase thereafter by 20% at 5% steps for years 2015-2019 then the abstraction continuous with that rates for the rest of the simulation period up to 2035.

While the problem of simulating the Gash river flow is best handled through a stochastic simulation process, this approach was abandoned due to time and data constraints for the option of using the average 10 day river stage obtained from the river stage data 2004-2014. The average annual total river flow is estimated to be about 950 million m^3 per year for the period between 1970 and 2012 and the 10 day average river stage values at the three stations of Gera, Kassala Bridge and Salam Alikum was estimated for the flood period (June – October) (Figure 4-8)

The calibrated model was subsequently used to compute the groundwater level values for the period between 2014 t0 2035. The results was analysed to compute the total aquifer recharge from the river as well as the long term impact of the current and projected development on the Gash River Basin by the year 2035.

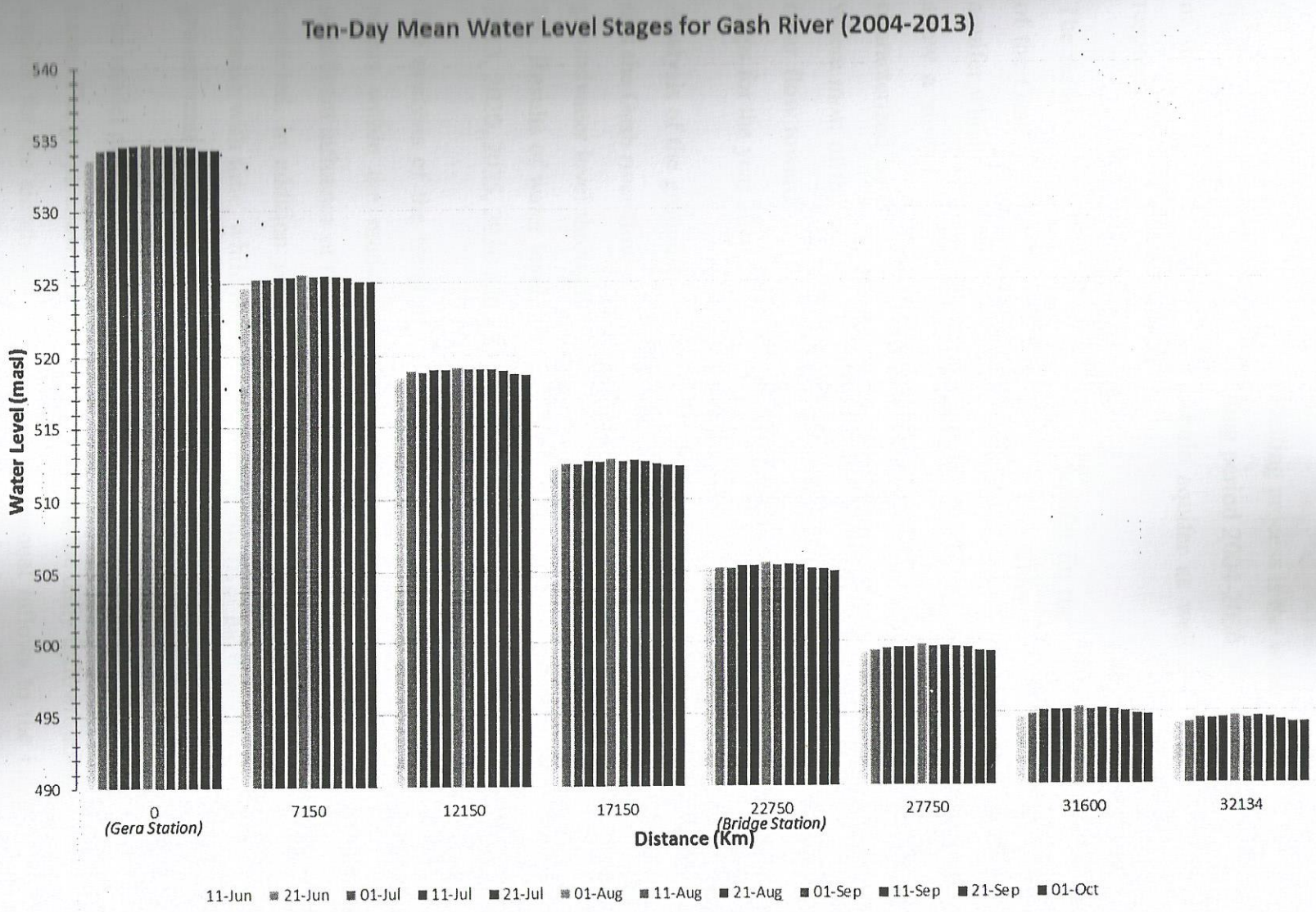


Figure 4-8: Average Ten Day Gash River Stage

5 MODEL RESULTS

One of the main outcomes of the modelling process is the water level within all of the aquifer for any time frame within the modelling period 2004-2030. This allows for the understanding of the flow dynamics within the whole aquifer as well as the prediction of the aquifer response to different stress scenarios.

The results show that the flow within the aquifer for the most part follows the flow direction of the Gash River, and that it is divided by the River Morphology. The Eastern part of the aquifer which is characterized by shallow aquifer depth and the presence of aquitard material show a slow flow in towards the North. East. The western part of the basin which is characterized by a deeper aquifer thickness and the presence of lesser aquitard material is where most of the horticultural development takes and the flow in the aquifer experiences a clear flow towards the west away from the river. This is clarified in the groundwater level maps for the year 2010 during the dry and rainy seasons (Figures 5-1 and 5-2)

Analysis of the groundwater level differences between the dry and rainy seasons have shown that the Gash river flow replenishes the Gash groundwater basin causing an average rise in the groundwater level throughout the aquifer in the order of one to two meters. (Figures5-3 to 5-16). Results of water level maps in the middle of the rainy season for selected years (2004 to 2013, 2020, 2025, 2030 and 2035) is given in Annex 3.

The analysis of the trend of the groundwater levels with time was conducted for selected points within the model boundary (Figure 5-17). Points close to the river have shown significant influence of the Gash River flood cycles while those away from the river were less impacted. In addition points toward the east of the project area have shown progressive increase with time, while those to the west of the river have displayed progressive decline of groundwater levels with time. (Figures 5-18)

The model also computes the inflows and outflows from the Gash River to the groundwater basin. The graph shown in Figure 5-19 displays the daily inflow/outflow from the river to the aquifer for the simulation period. Net river annual inflows to the basin were subsequently calculated for each year. For the period from 2004 to 2013 the annual net Basin recharge was found to be ranging from a minimum of 44 MCM to a maximum of 101 MCM with an average of 72.9 MCM per year. For the period 2014 to 2035 the mean was found to be 66.5

MCM per year. Figure 5-20 shows the total annual groundwater recharge to the basin from the Gash River for the whole simulation period. Given that the total annual abstraction rates from the aquifer are currently about 100 million m^3 per year, it can be concluded that about 20 to 30 million m^3 are being annually depleted from the Gash Basin storage. This Figure is bound to increase with future increase in groundwater abstractions.

The investigated scenario shows that the Gash River is expected to experience a decline of groundwater levels in the order of one to 2.5 m by 2020 compared to groundwater levels in 2013 and that this is expected to exacerbate to a range of 2-5 m by the year 2035.

In addition to the overall water balance analysis conducted for the whole basin area, additional zonal analysis was conducted where the aquifer was divided into three zones (Figure 5-21) and water balance analysis was conducted for each zone separately. Zone 1 was delineated from the Northern tip of the aquifer to the location of Kassla Bridge, Zone 2 was delineated from Kassala Bridge south to Taka mountain and Zone 3 was delineates as the section of the aquifer south of the Taka Mountain. Figure 5-22 shows the contribution of each of the above zones to the total groundwater abstractions.

The river inflow and outflow components are shown in Table 5-1 which shows that most of the river interaction with the basin is in zone 3 and the most of the net river inflow comes through Zone 2.

Inspite of its shallow thickness and relatively lower storage volume, Zone 3 receives most of the inflow from the Gash River during the flow and builds a gradient that drives the groundwater within the basin towards the North thus contributing significantly to the recharge of the Gash Basin. Excess waters that cannot be driven to the deeper sections of the aquifer due to loss of gradient flows back to the river as outflow. About 32% of the total basin recharge is attributed to inflow from the river via zone 3 while about 58 % is attributed to inflow from the river via zone 2

The Gash Basin benefits more in terms of recharge from long duration low volume floods rather than short duration large flow floods.

Table 5-1: River - Aquifer Inflow / Outflow (MCM) for Different Zones (2004 – 2013)

Year	zone1			zone2			zone3			Total Net Inflow
	Inflow	Outflow	Net recharge	Inflow	Outflow	Net recharge	Inflow	Outflow	Net recharge	
2004	44	18	**26**	35	1	**34**	131	107	**24**	**85**
2005	58	33	**25**	47	2	**46**	149	119	**30**	**101**
2006	55	48	**6**	42	5	**37**	132	122	**10**	**53**
2007	51	46	**5**	40	4	**36**	138	120	**18**	**58**
2008	53	46	**7**	52	6	**46**	167	132	**35**	**87**
2009	60	52	**8**	53	9	**44**	159	136	**23**	**75**
2010	44	47	**-3**	52	9	**43**	161	134	**27**	**67**
2011	65	53	**12**	57	12	**45**	165	135	**30**	**87**
2012	50	50	**0**	40	8	**31**	146	134	**12**	**44**
2013	53	51	**2**	48	11	**38**	142	120	**22**	**62**

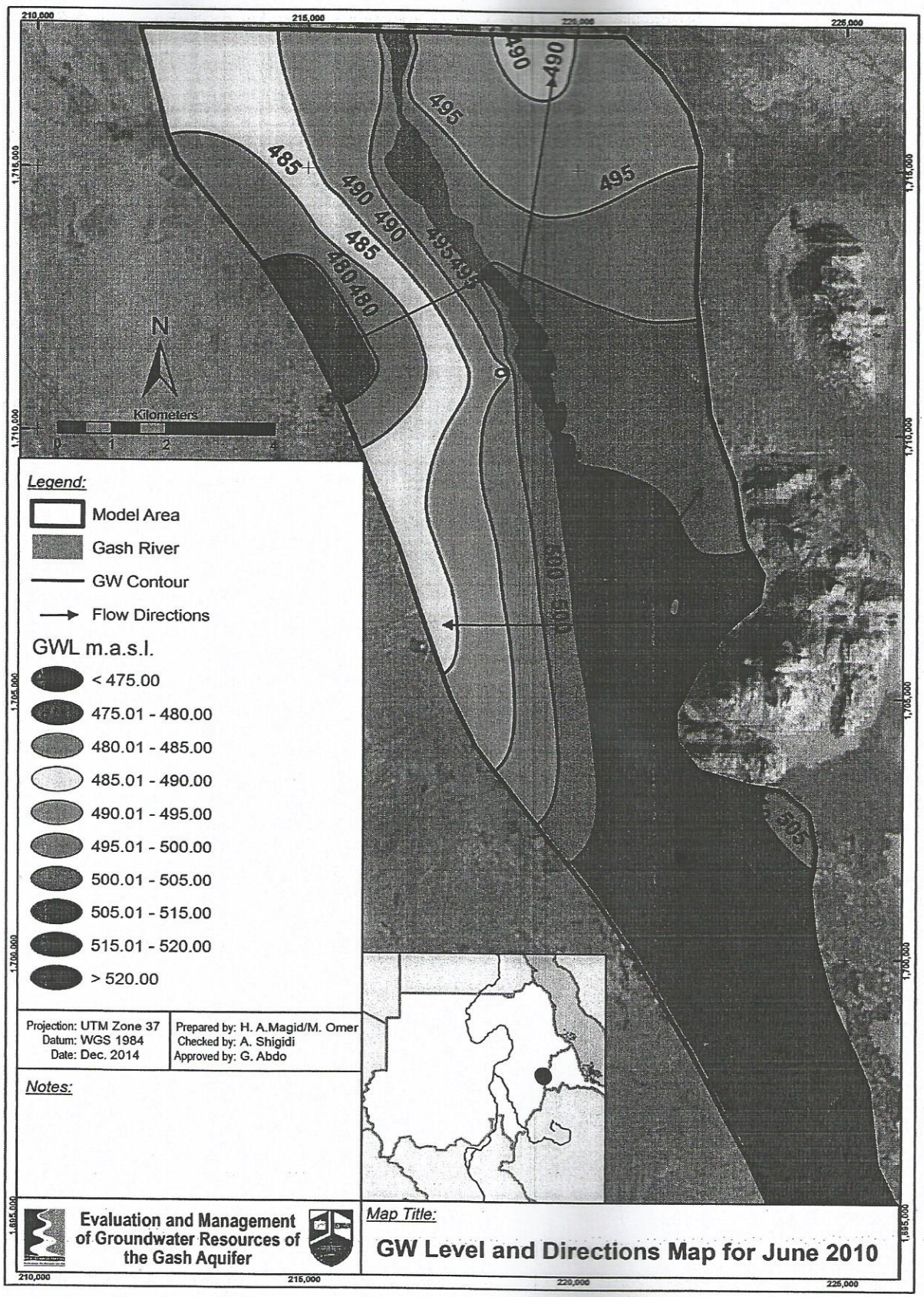
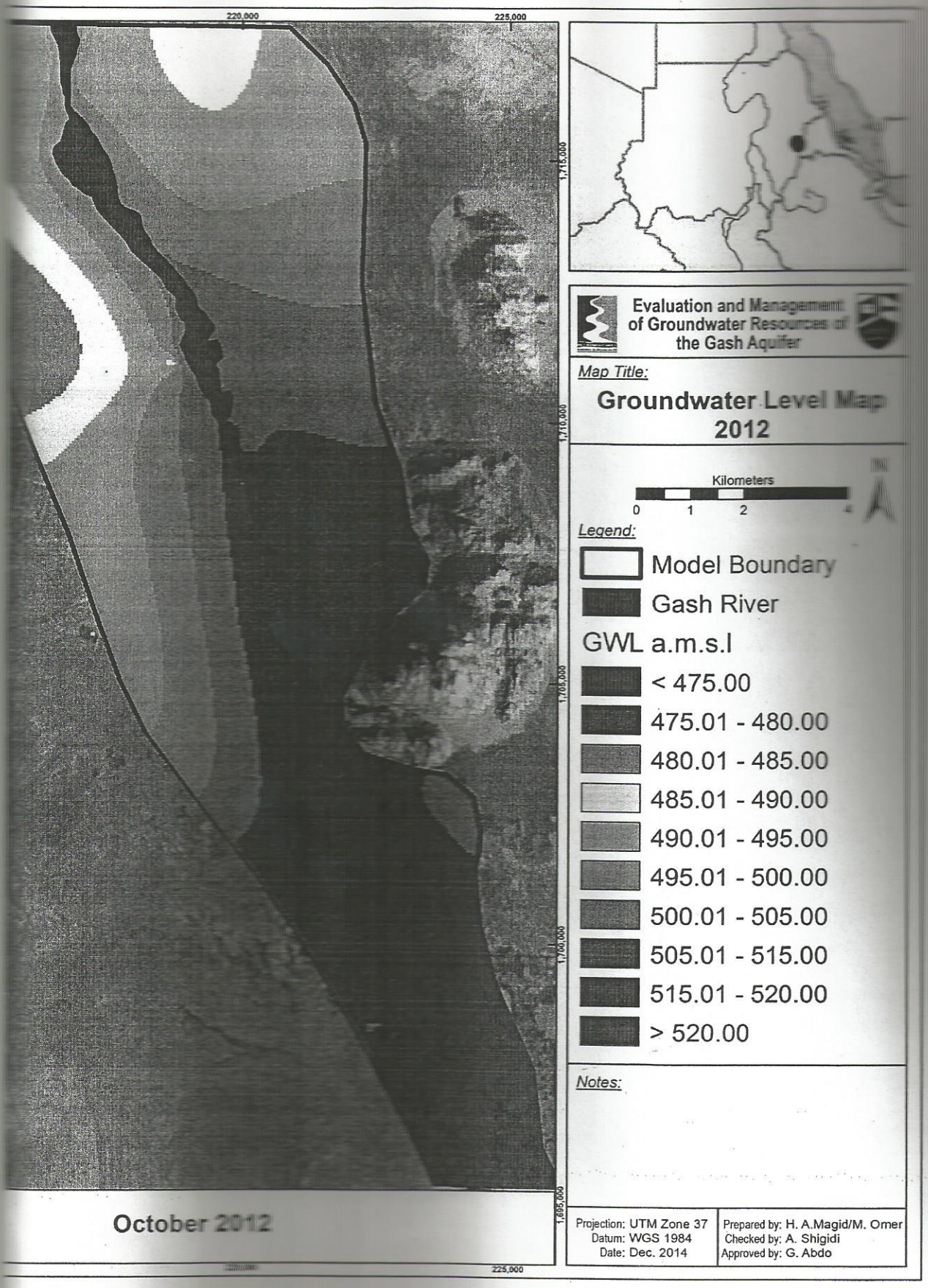


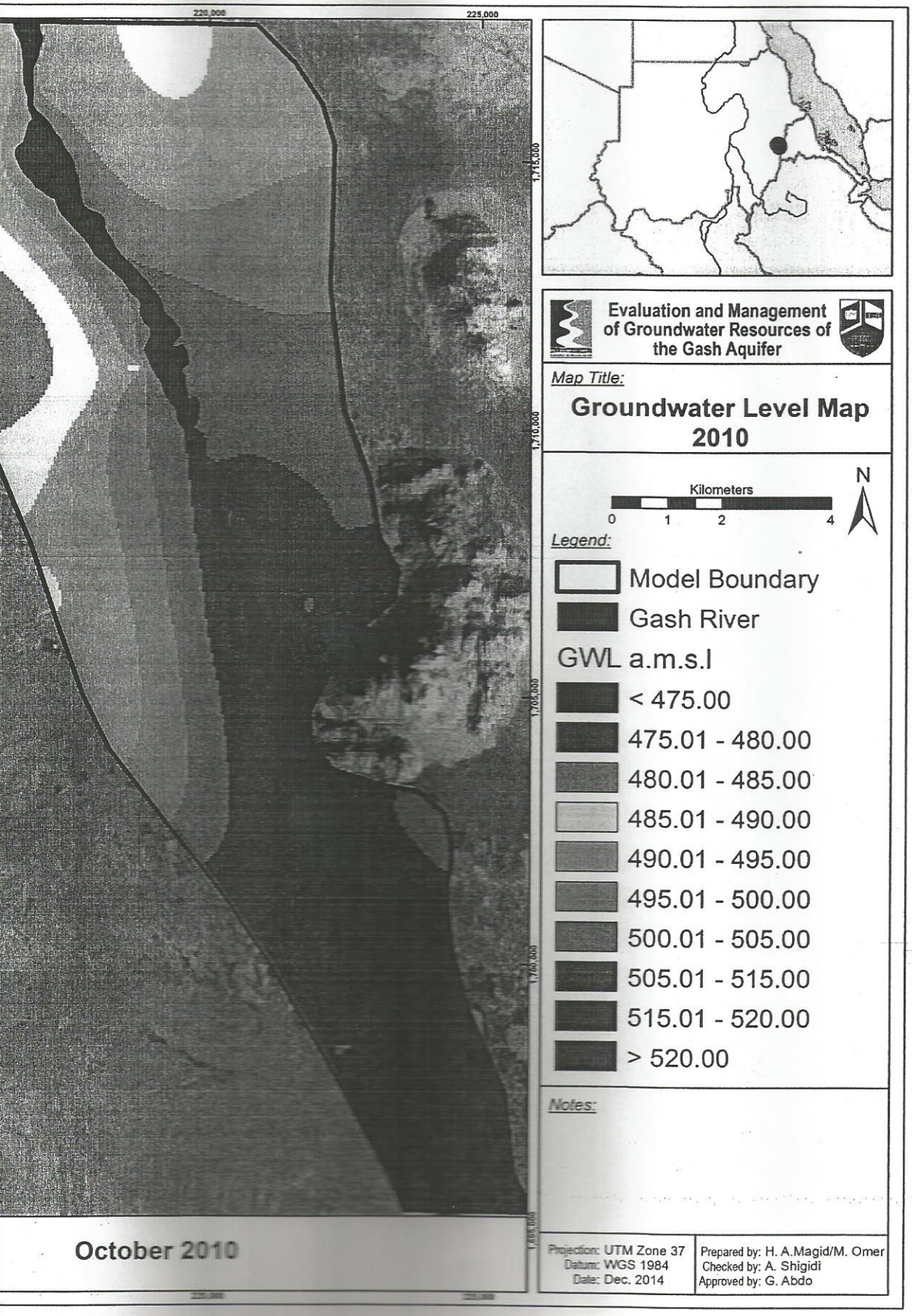
Figure 5-1: Groundwater Level and Directions Map for June 2010

Figure 5-11: Groundwater



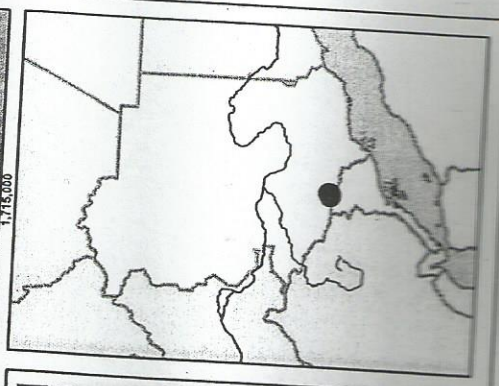
Level Map for Year 2012

Figure 5-10: Groundwa



vel Map for Year 2011

Figure 5-9: Groundwater Le



Evaluation and Management of Groundwater Resources of the Gash Aquifer

Map Title:

Groundwater Level Map 2010

Kilometers

0 1 2 4

N

Legend:

- Model Boundary
- Gash River

GWL a.m.s.l

- < 475.00
- 475.01 - 480.00
- 480.01 - 485.00
- 485.01 - 490.00
- 490.01 - 495.00
- 495.01 - 500.00
- 500.01 - 505.00
- 505.01 - 515.00
- 515.01 - 520.00
- > 520.00

Notes:

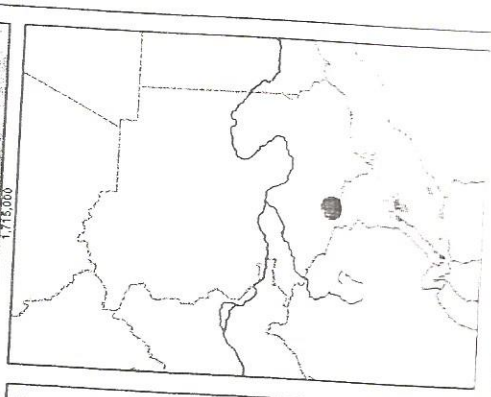
October 2010

Projection: UTM Zone 37
Datum: WGS 1984
Date: Dec. 2014

Prepared by: H. A. Magzoub, Omer
Checked by: A. Singer
Approved by: G. Alpert

Figure 5-9: Groundwater Level M

October 2010



Evaluation and Management of Groundwater Resources of the Gash Aquifer

Map Title:

Groundwater Level Map 2010

Kilometers
0 1 2 4

N

Legend:

- Model Boundary
- Gash River

GWL a.m.s.l

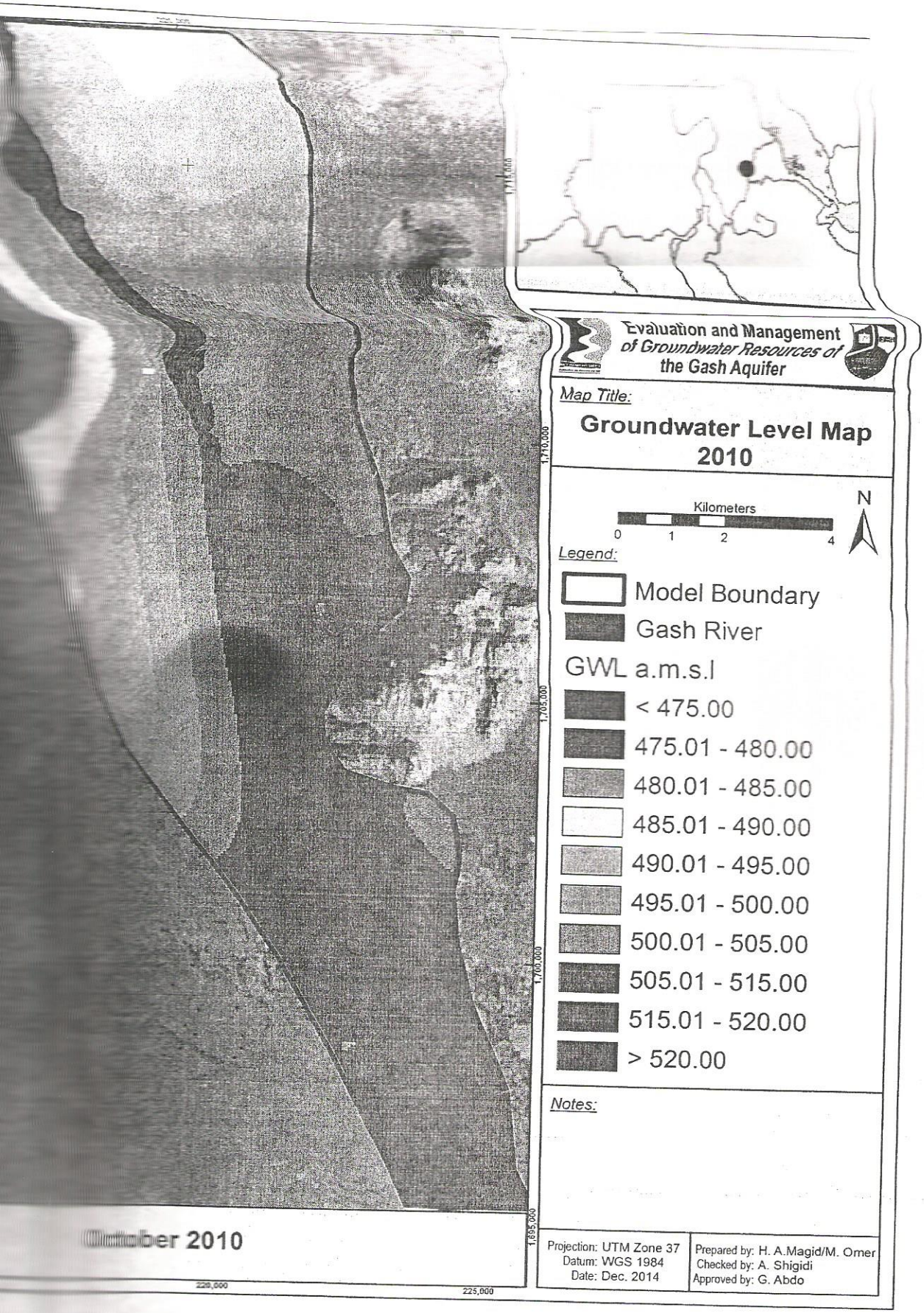
- < 475.00
- 475.01 - 480.00
- 480.01 - 485.00
- 485.01 - 490.00
- 490.01 - 495.00
- 495.01 - 500.00
- 500.01 - 505.00
- 505.01 - 515.00
- 515.01 - 520.00
- > 520.00

Notes:

Projection: UTM Zone 37
Datum: WGS 1984
Date: Dec. 2014

Prepared by: H. A.Magid/M. Omer
Checked by: A. Shigidi
Approved by: G. Abdo

Map for Year 2010


Evaluation and Management
of Groundwater Resources of
the Gash Aquifer
Map Title:
Groundwater Level Map
2010
Kilometers
0 1 2 4
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Legend:
Model Boundary
Gash River
GWL a.m.s.l
< 475.00
475.01 - 480.00
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500.01 - 505.00
505.01 - 515.00
515.01 - 520.00
> 520.00
Notes:
Projection: UTM Zone 37
Datum: WGS 1984
Date: Dec. 2014
Prepared by: H. A.Magid/M. Omer
Checked by: A. Shigidi
Approved by: G. Abdo
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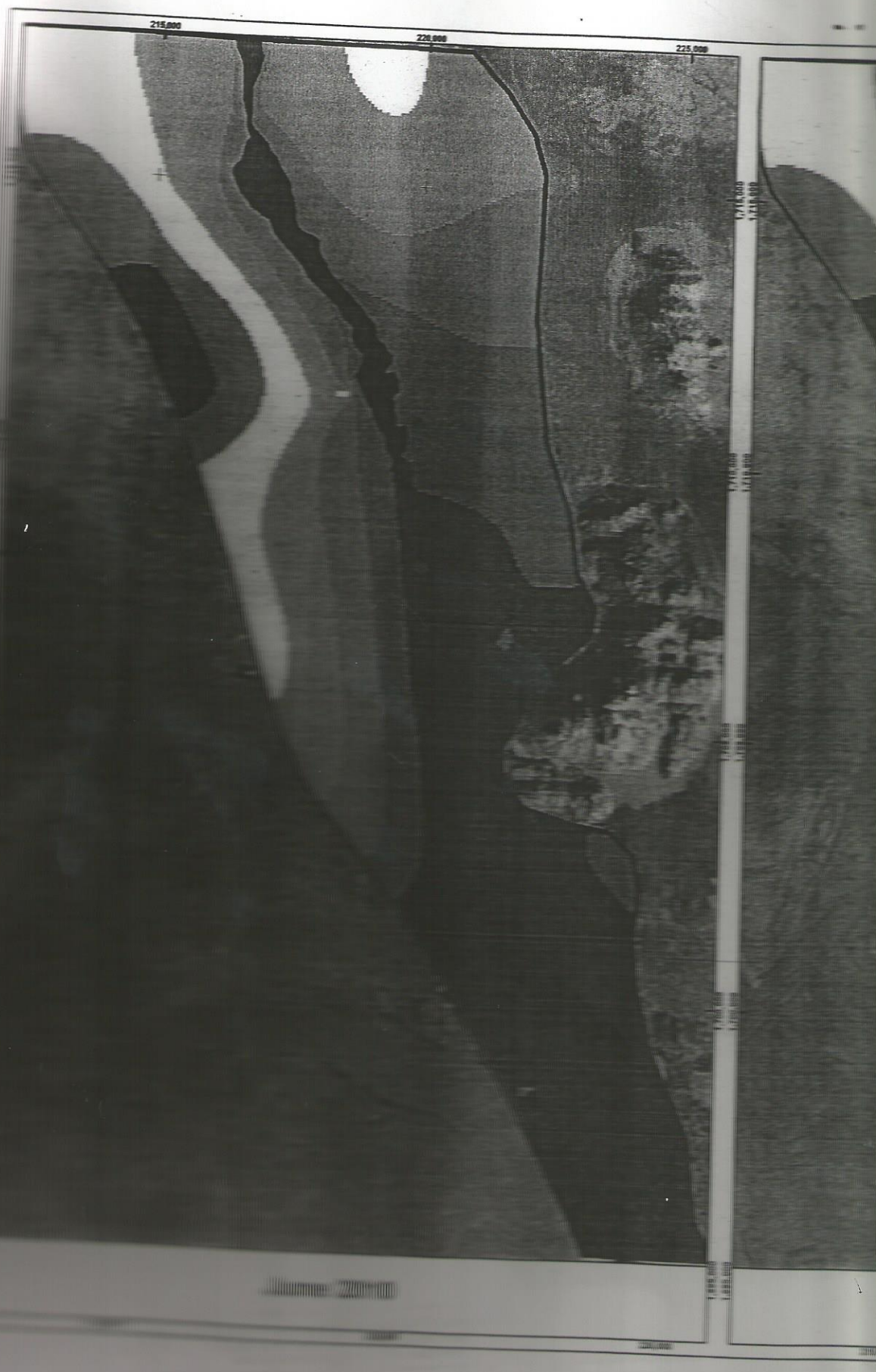
225,000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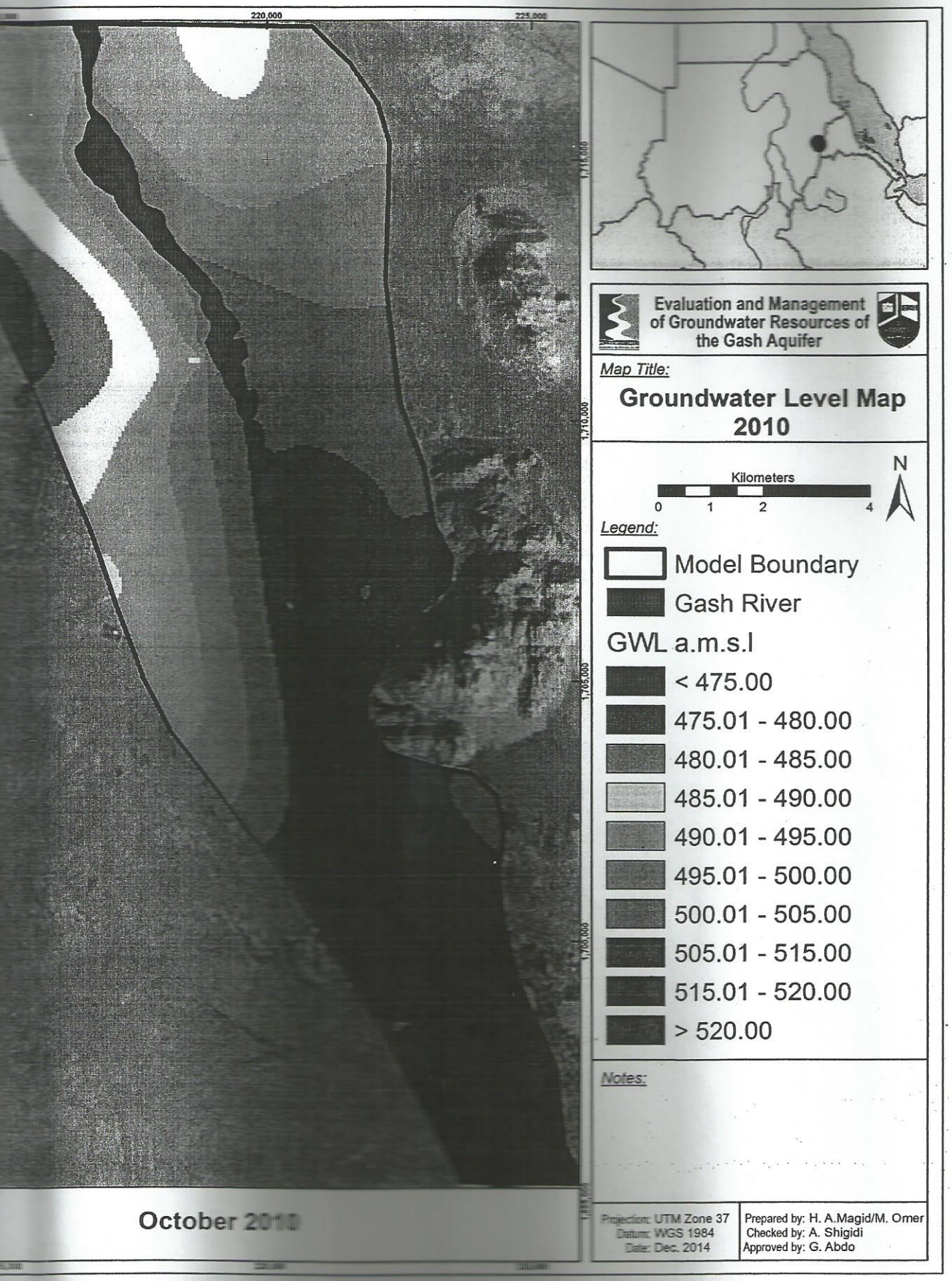
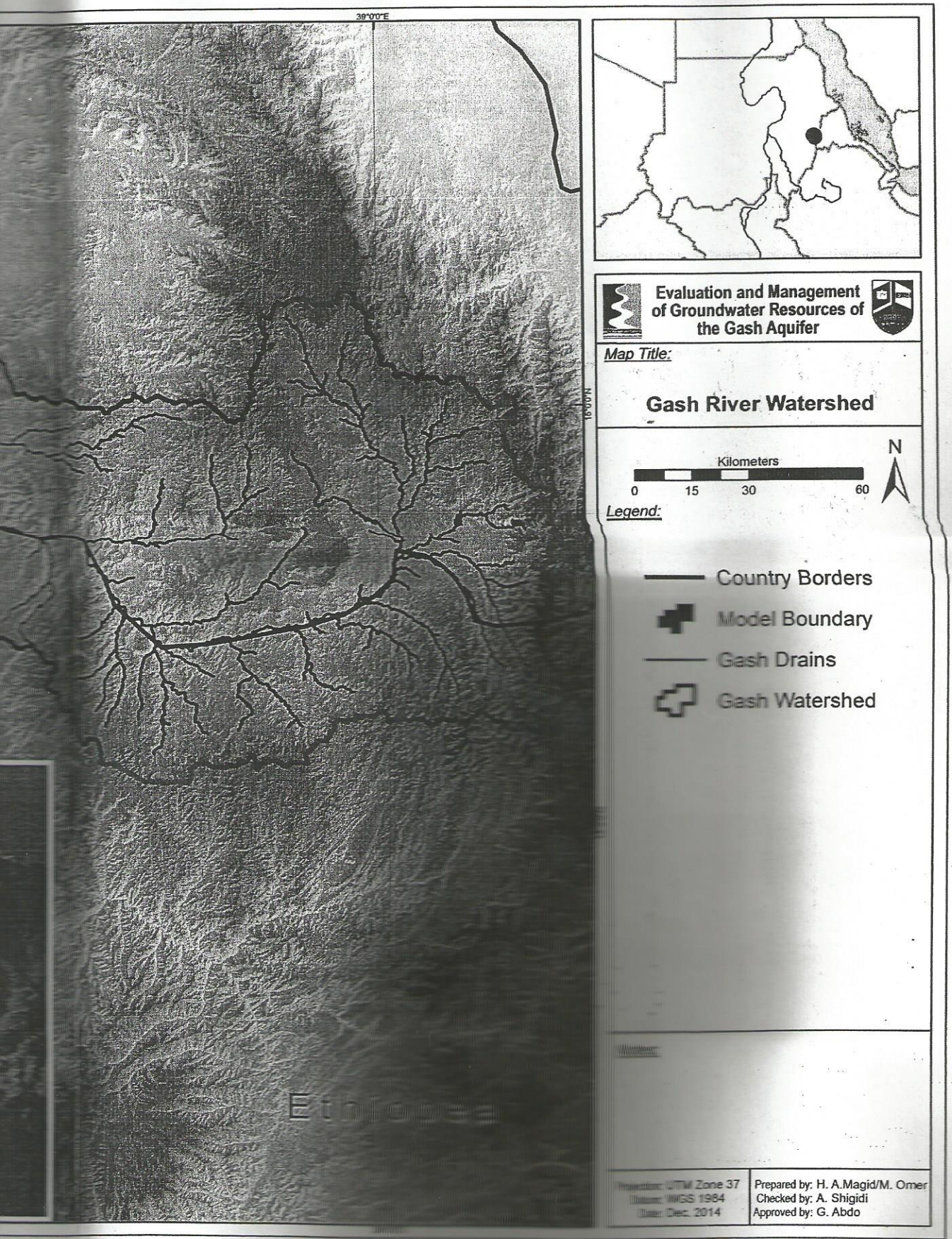
220,000
225,000



er Level Map for Year 2010

Figure 5-9: Groundwa



Evaluation and Management of Groundwater Resources of the Gash Aquifer

Map Title:

Gash River Watershed

Kilometers

0 15 30 60

N

Legend:

- Country Borders
- Model Boundary
- Gash Drains
- Gash Watershed

Projection: UTM Zone 37
Datum: WGS 1984
Date: Dec. 2014

Prepared by: H. A.Magid/M. Omer
Checked by: A. Shigidi
Approved by: G. Abdo

atershed of the Gash River

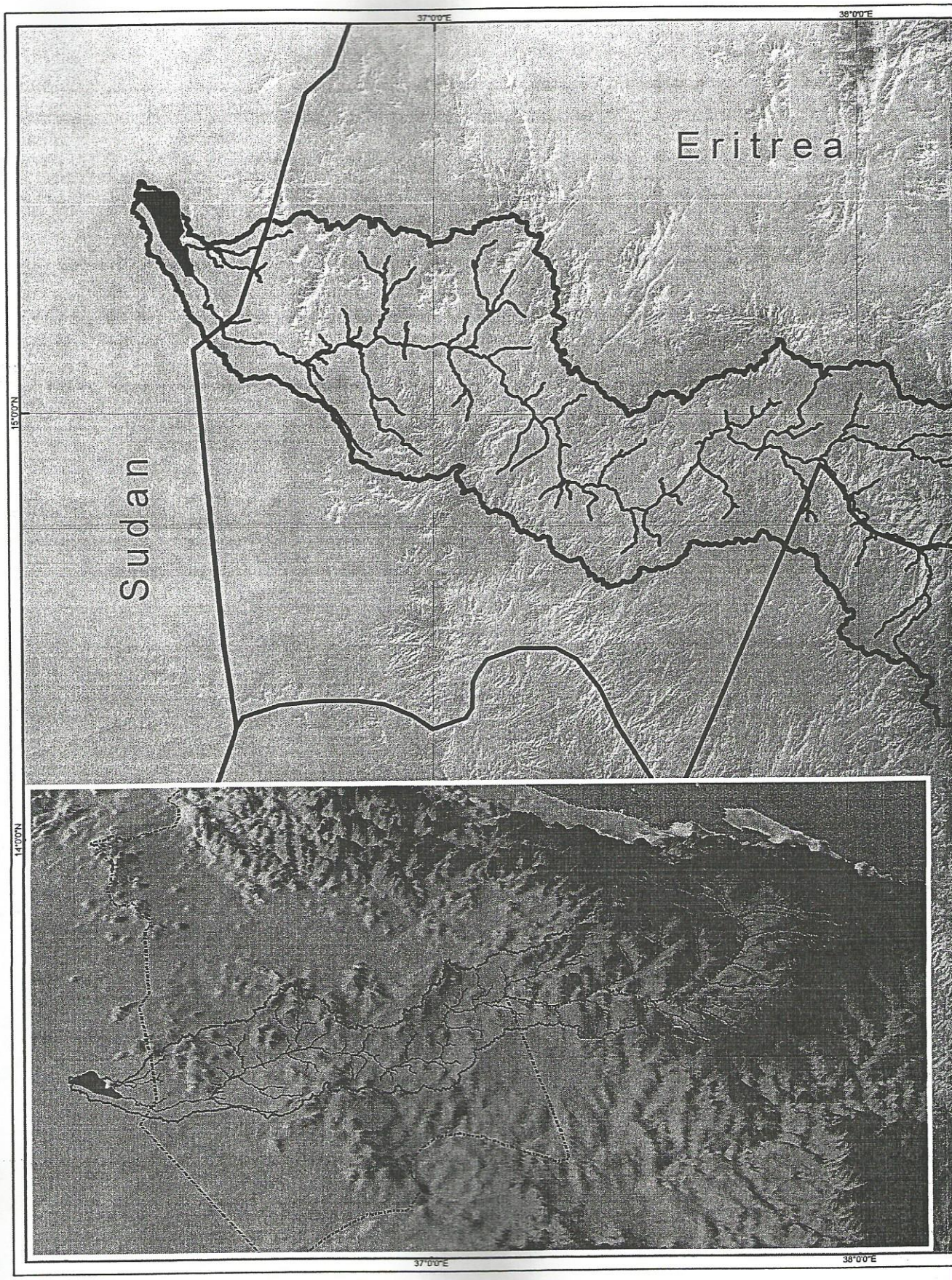
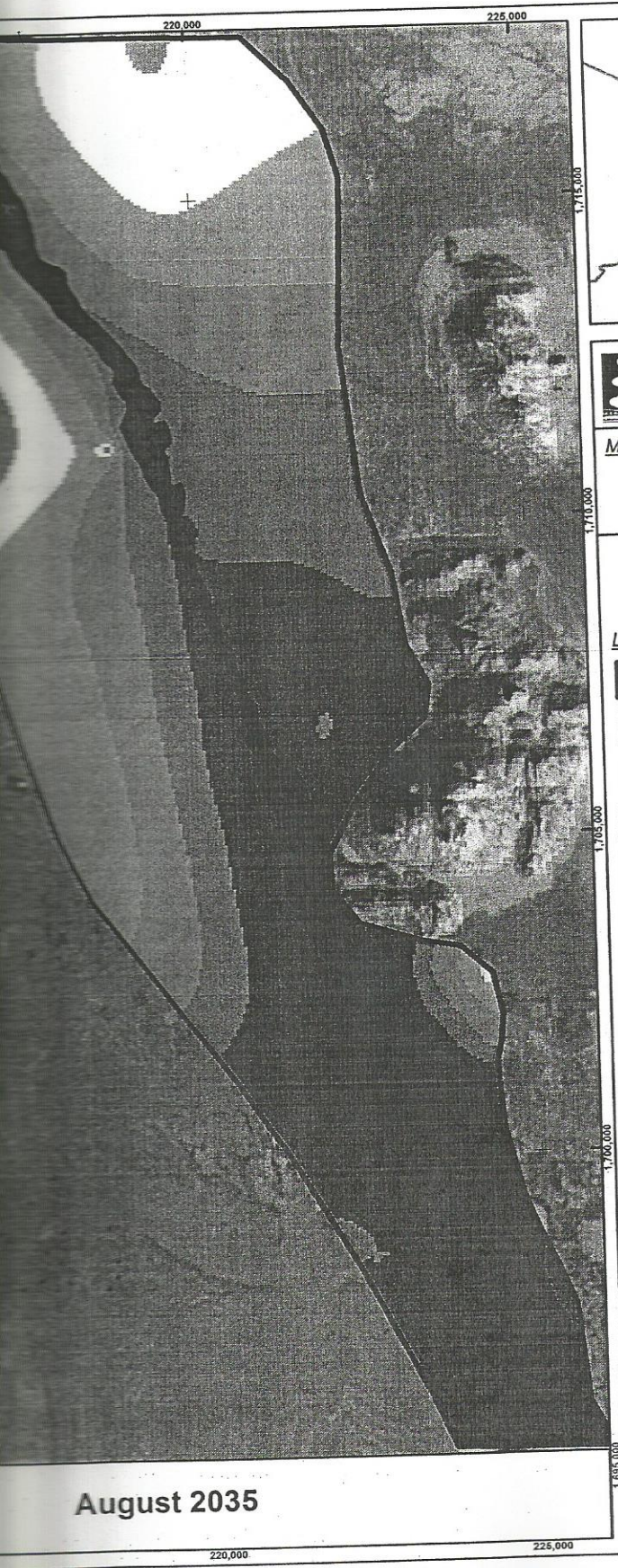
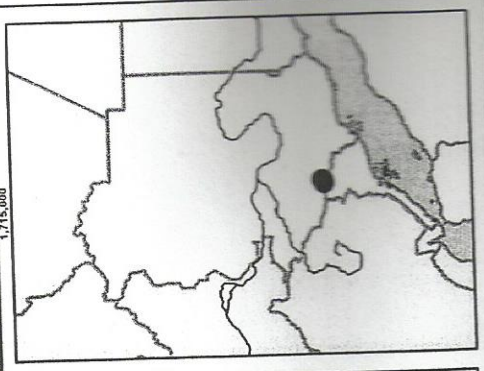


Figure 1-1: Watershe





Evaluation and Management of Groundwater Resources of the Gash Aquifer

Map Title:

Groundwater Level Map

Kilometers
0 1 2 4

N

Legend:

- Model Boundary
- Gash River

GWL m.a.s.l.

- < 475.00
- 475.01 - 480.00
- 480.01 - 485.00
- 485.01 - 490.00
- 490.01 - 495.00
- 495.01 - 500.00
- 500.01 - 505.00
- 505.01 - 515.00
- 515.01 - 520.00
- > 520.00

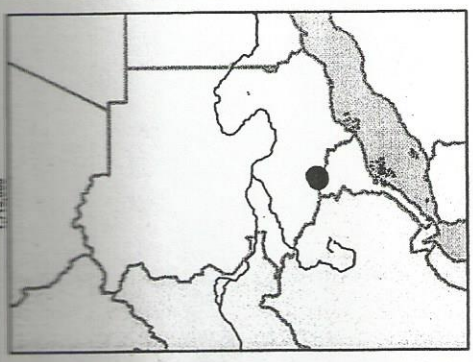
Notes:

Projection: UTM Zone 37
Datum: WGS 1984
Date: Dec. 2014

Prepared by: H. A.Magid/M. Omer
Checked by: A. Shigidi
Approved by: G. Abdo


215,000
220,000
1,715,000
1,710,000
1,705,000
1,700,000
1,695,000
August 2030


215,000
220,000
225,000
1,715,000
1,710,000
1,705,000
1,700,000
1,695,000
August 2020



Evaluation and Management of Groundwater Resources of the Gash Aquifer

Map Title:

Groundwater Level Map

Kilometers
0 1 2 4

N

Legend:

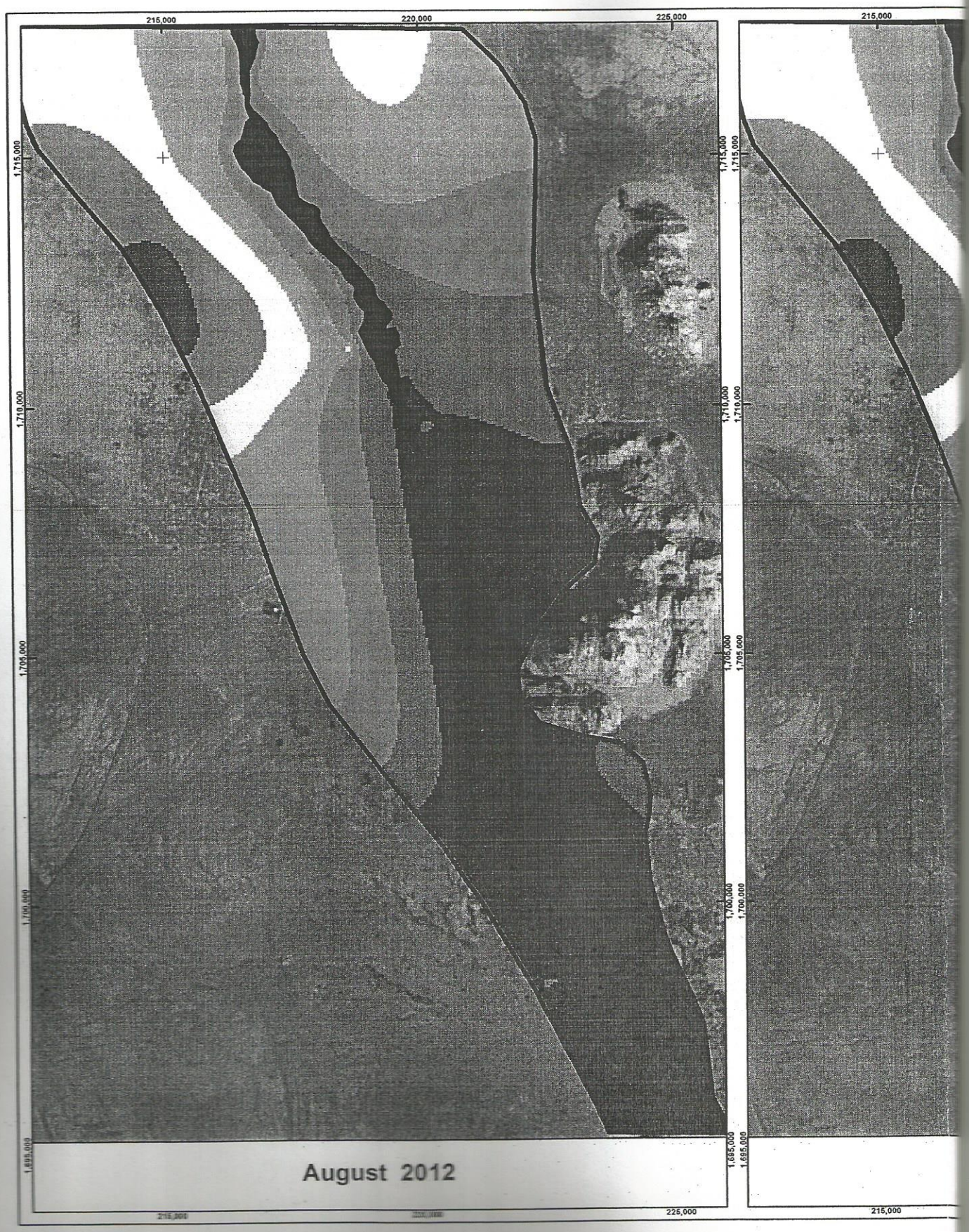
- Model Boundary
- Gash River

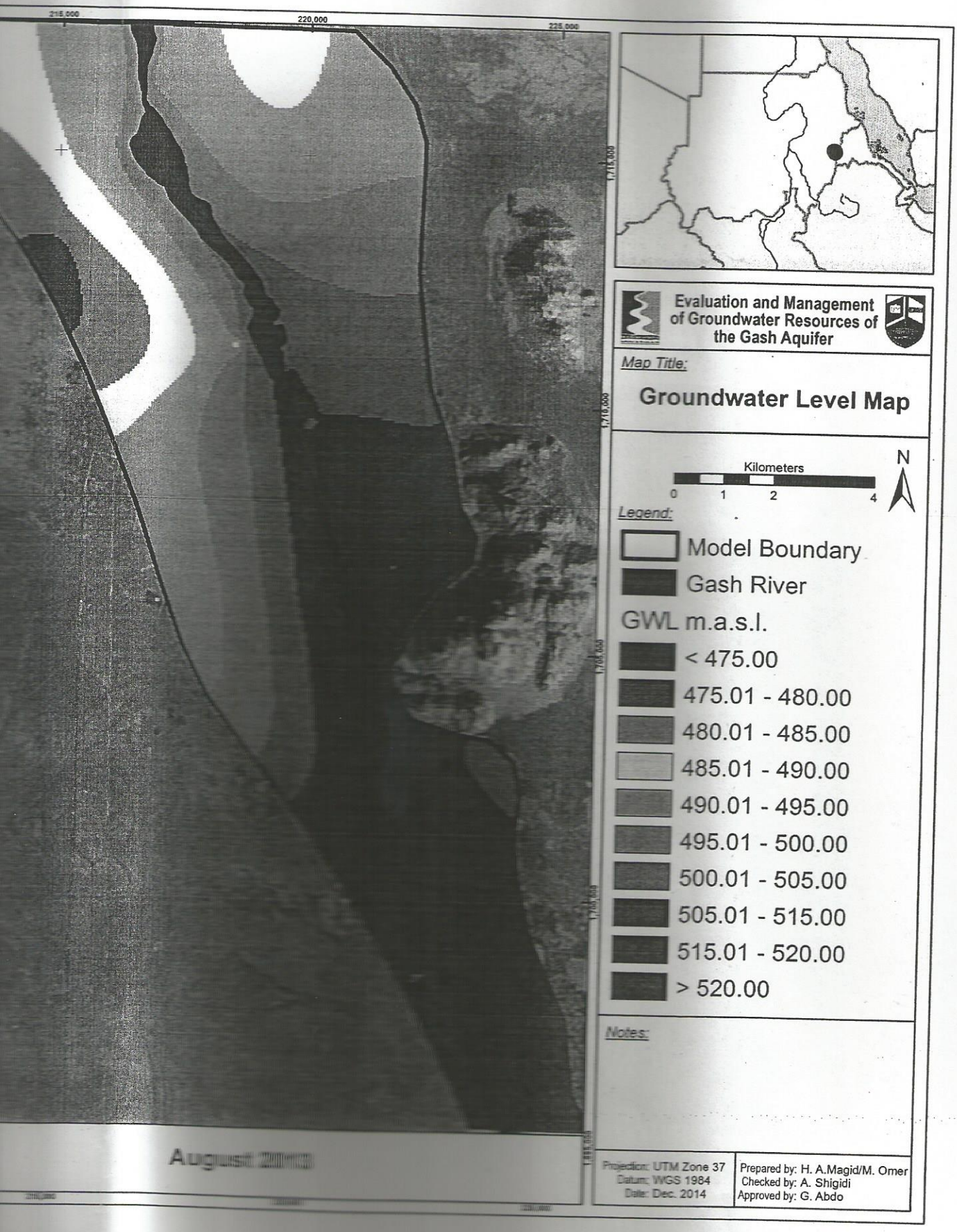
GWL m.a.s.l.

- < 475.00
- 475.01 - 480.00
- 480.01 - 485.00
- 485.01 - 490.00
- 490.01 - 495.00
- 495.01 - 500.00
- 500.01 - 505.00
- 505.01 - 515.00
- 515.01 - 520.00
- > 520.00

Notes:

Projection: UTM Zone 37 Datum: WGS 1984 Date: Dec. 2014	Prepared by: H. A.Magid/M. Omer Checked by: A. Shigidi Approved by: G. Abdo


215,000
220,000
225,000
1,715,000
1,710,000
1,705,000
1,700,000
1,695,000
August 2012



Evaluation and Management of Groundwater Resources of the Gash Aquifer

Map Title:

Groundwater Level Map

Kilometers
0 1 2 4

N

Legend:

- Model Boundary
- Gash River

GWL m.a.s.l.

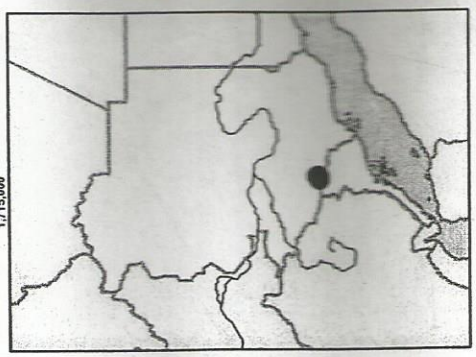
- < 475.00
- 475.01 - 480.00
- 480.01 - 485.00
- 485.01 - 490.00
- 490.01 - 495.00
- 495.01 - 500.00
- 500.01 - 505.00
- 505.01 - 515.00
- 515.01 - 520.00
- > 520.00

Notes:

Projection: UTM Zone 37
Datum: WGS 1984
Date: Dec. 2014

Prepared by: H. A.Magid/M. Omer
Checked by: A. Shigidi
Approved by: G. Abdo


216,000
220,000
225,000
1,715,000
1,710,000
1,705,000
1,700,000
1,695,000
215,000
220,000
225,000
August 2010



Evaluation and Management of Groundwater Resources of the Gash Aquifer

Map Title:

Groundwater Level Map

Kilometers
0 1 2 4

N

Legend:

- Model Boundary
- Gash River

GWL m.a.s.l.

- < 475.00
- 475.01 - 480.00
- 480.01 - 485.00
- 485.01 - 490.00
- 490.01 - 495.00
- 495.01 - 500.00
- 500.01 - 505.00
- 505.01 - 515.00
- 515.01 - 520.00
- > 520.00

Notes:

Projection: UTM Zone 37 Datum: WGS 1984 Date: Dec. 2014	Prepared by: H. A.Magid/M. Omer Checked by: A. Shigidi Approved by: G. Abdo


215,000
220,000
225,000
1,715,000
1,710,000
1,705,000
1,700,000
1,695,000
August 2008

Evaluation and Management of Groundwater Resources of the Gash Aquifer

Map Title:

Groundwater Level Map

Kilometers

0 1 2 4

N

Legend:

- Model Boundary
- Gash River

GWL m.a.s.l.

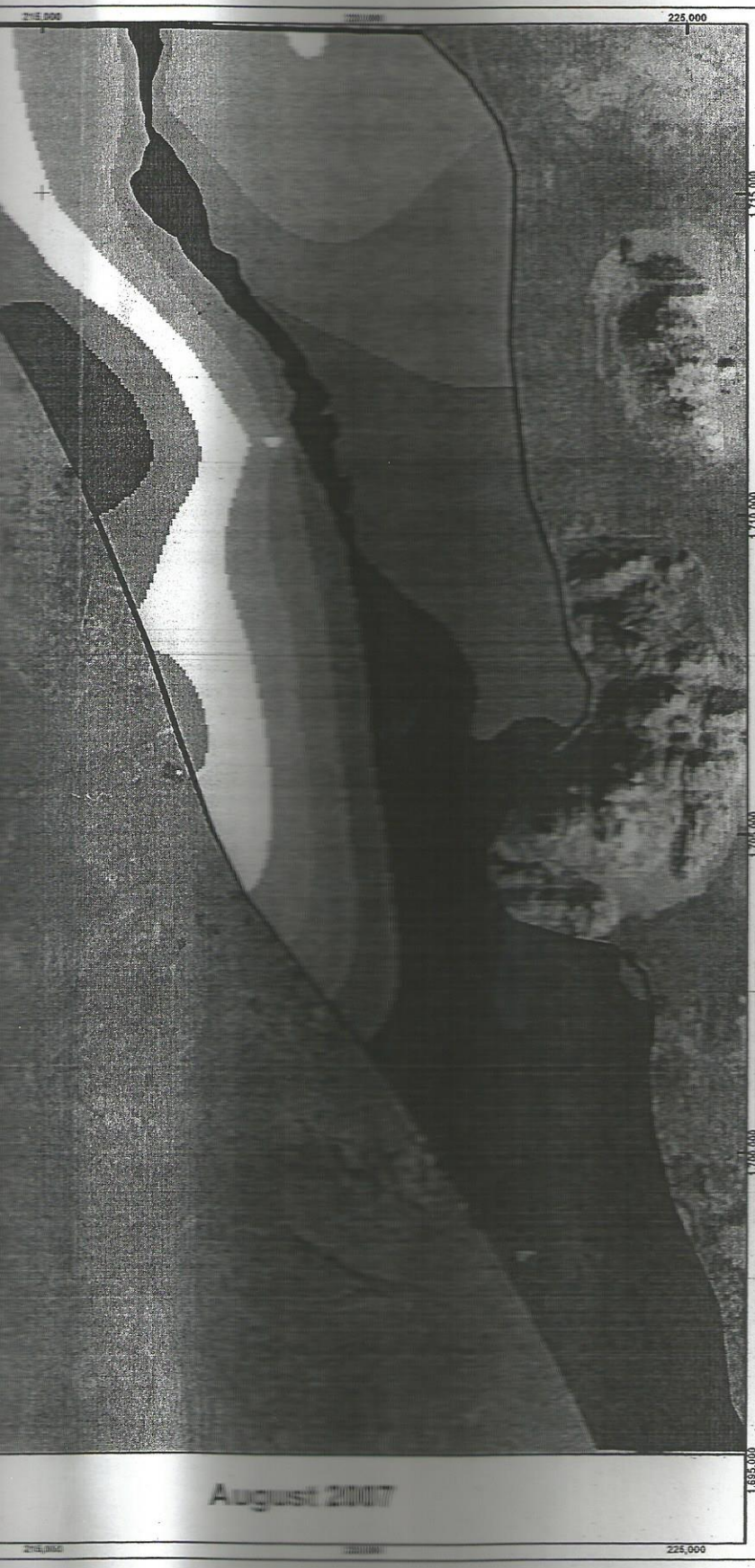
- < 475.00
- 475.01 - 480.00
- 480.01 - 485.00
- 485.01 - 490.00
- 490.01 - 495.00
- 495.01 - 500.00
- 500.01 - 505.00
- 505.01 - 515.00
- 515.01 - 520.00
- > 520.00

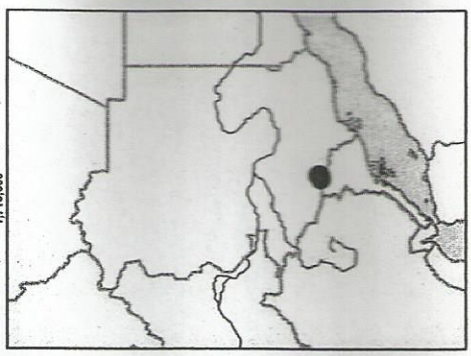
Notes:

Projection: UTM Zone 37
Datum: WGS 1984
Date: Dec. 2014

Prepared by: H. A./Magid/M. Omer
Checked by: A. Shigidi
Approved by: G. Abdo


216,000
220,000
225,000
1,715,000
1,710,000
1,705,000
1,700,000
1,695,000
August 2006





Evaluation and Management of Groundwater Resources of the Gash Aquifer

Map Title:

Groundwater Level Map

Kilometers
0 1 2 4

N

Legend:

- Model Boundary
- Gash River

GWL m.a.s.l.

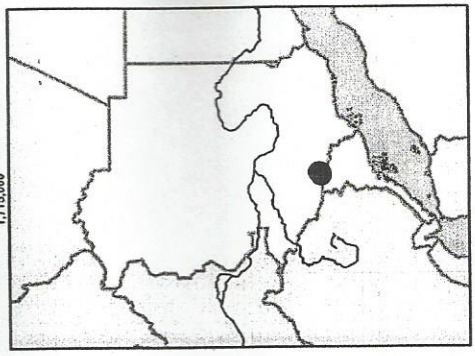
- < 475.00
- 475.01 - 480.00
- 480.01 - 485.00
- 485.01 - 490.00
- 490.01 - 495.00
- 495.01 - 500.00
- 500.01 - 505.00
- 505.01 - 515.00
- 515.01 - 520.00
- > 520.00

Notes:

Projection: UTM Zone 37
Datum: WGS 1984
Date: Dec. 2014

Prepared by: H. A.Magid/M. Omer
Checked by: A. Shigidi
Approved by: G. Abdo

Figure 5-12: Groundwa



Evaluation and Management of Groundwater Resources of the Gash Aquifer

Map Title:

Groundwater Level Map 2013

Kilometers

0 1 2 4

N

Legend:

- Model Boundary
- Gash River

GWL a.m.s.l

- < 475.00
- 475.01 - 480.00
- 480.01 - 485.00
- 485.01 - 490.00
- 490.01 - 495.00
- 495.01 - 500.00
- 500.01 - 505.00
- 505.01 - 515.00
- 515.01 - 520.00
- > 520.00

Notes:

Projection: UTM Zone 37 Datum: WGS 1984 Date: Dec. 2014	Prepared by: H. A.Magid/M. Omer Checked by: A. Shigidi Approved by: G. Abdo

water Level Map for Year 2013

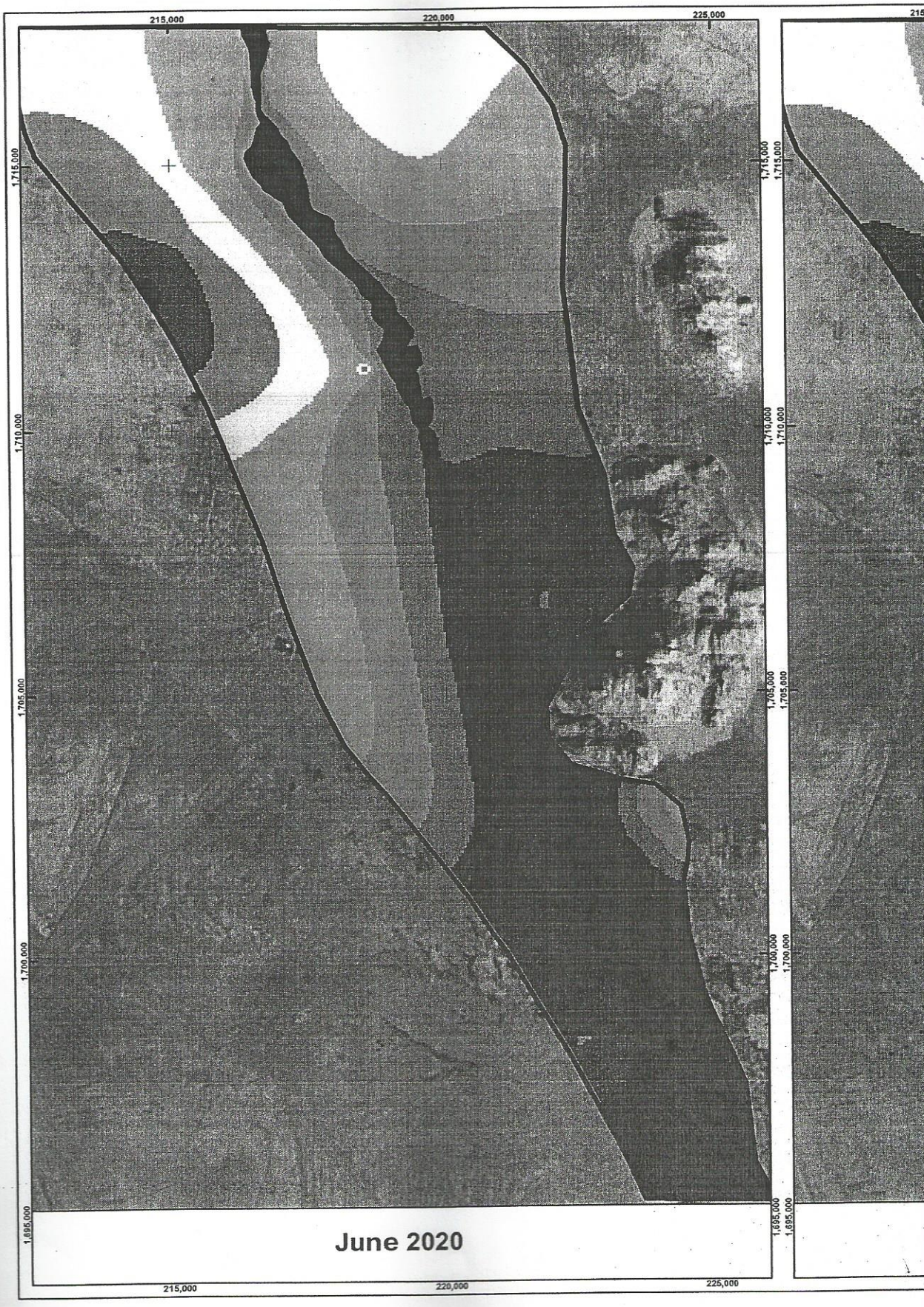
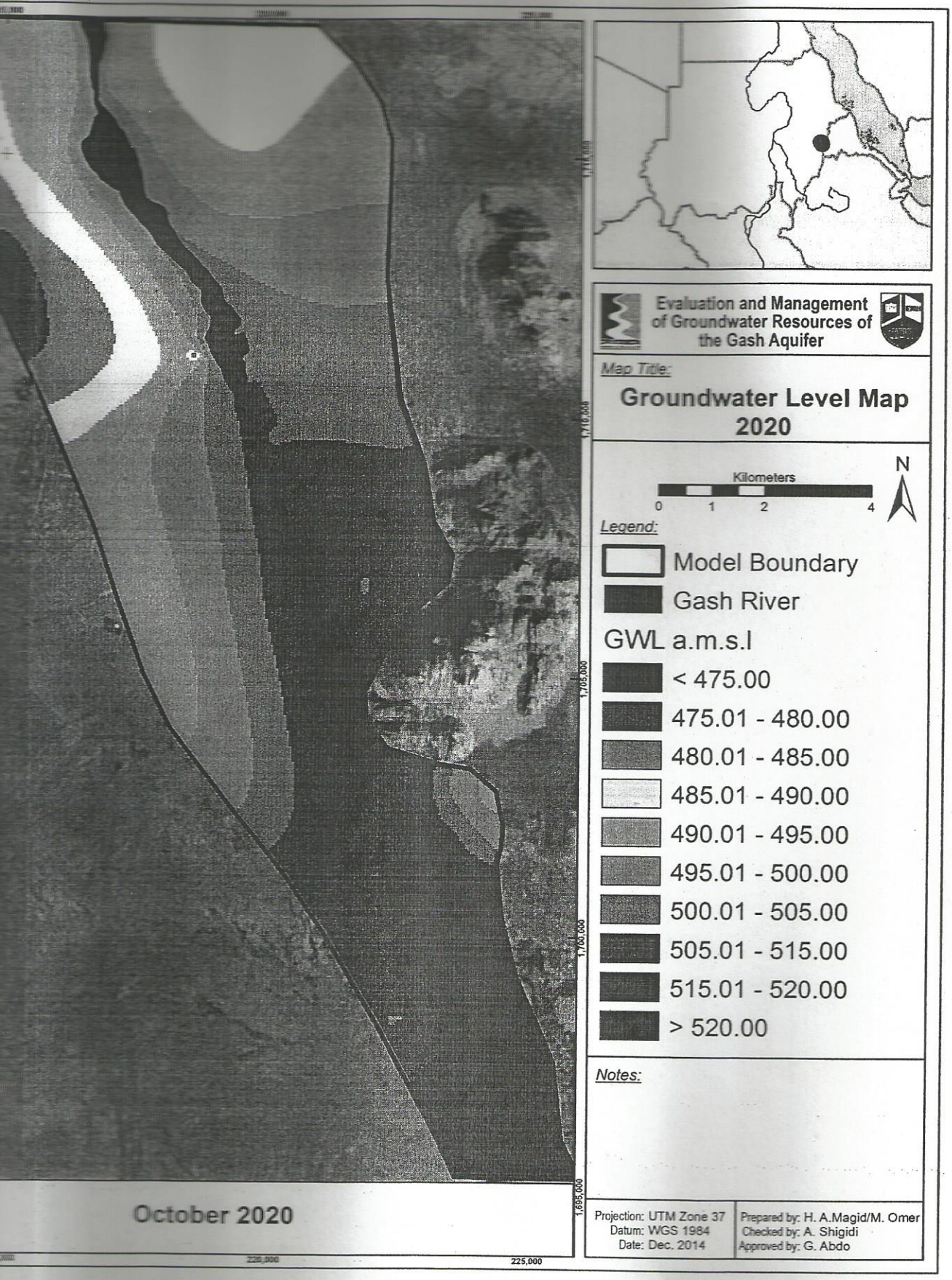
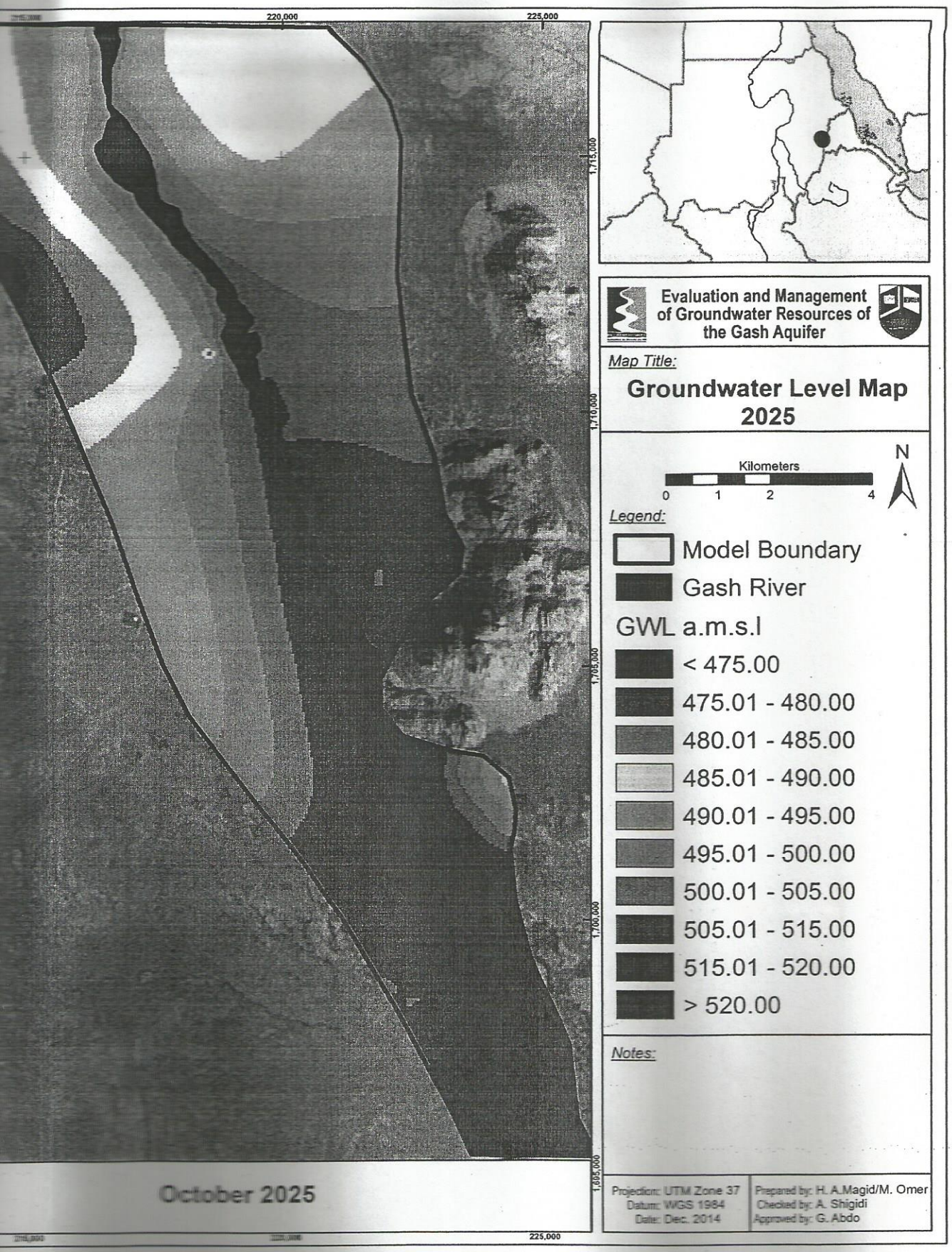


Figure 5-13: Groundw



er Level Map for Year 2020

Figure 5-14: Groundwa



Evaluation and Management of Groundwater Resources of the Gash Aquifer

Map Title:

Groundwater Level Map 2025

Kilometers

0 1 2 4

N

Legend:

- Model Boundary
- Gash River

GWL a.m.s.l

- < 475.00
- 475.01 - 480.00
- 480.01 - 485.00
- 485.01 - 490.00
- 490.01 - 495.00
- 495.01 - 500.00
- 500.01 - 505.00
- 505.01 - 515.00
- 515.01 - 520.00
- > 520.00

Notes:

Projection: UTM Zone 37 Datum: WGS 1984 Date: Dec. 2014	Prepared by: H. A.Magid/M. Omer Checked by: A. Shigidi Approved by: G. Abdo

water Level Map for Year 2025

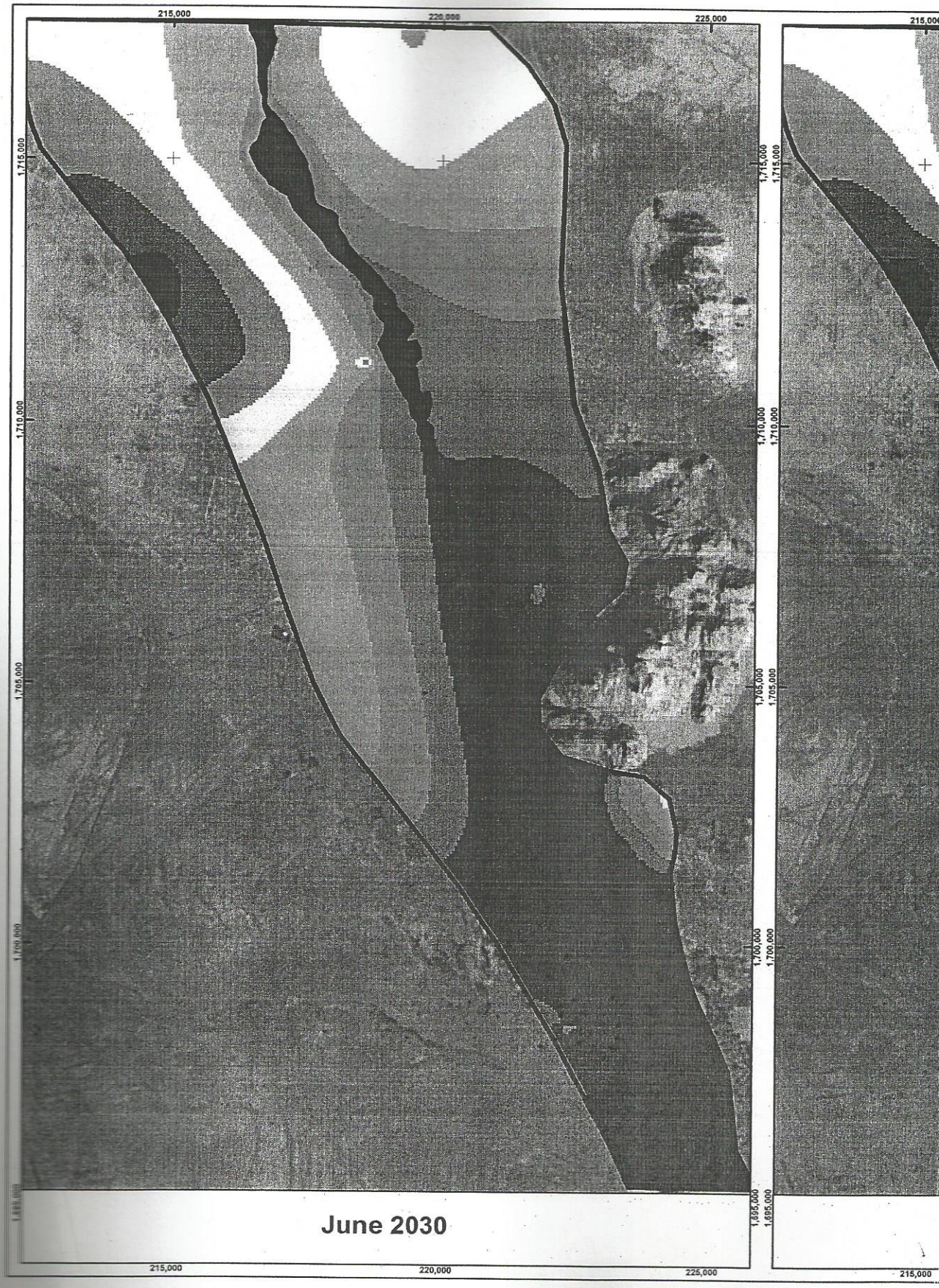
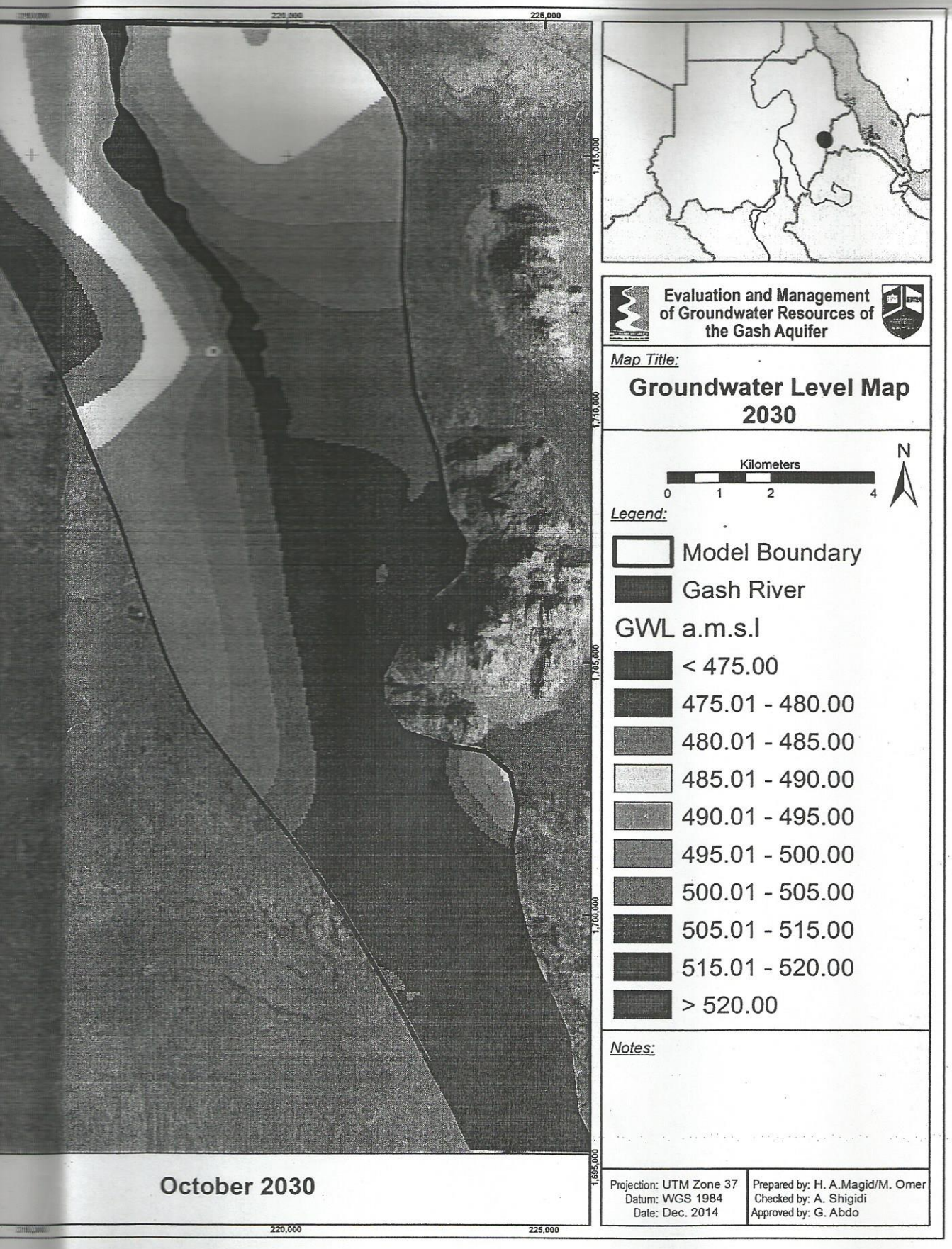
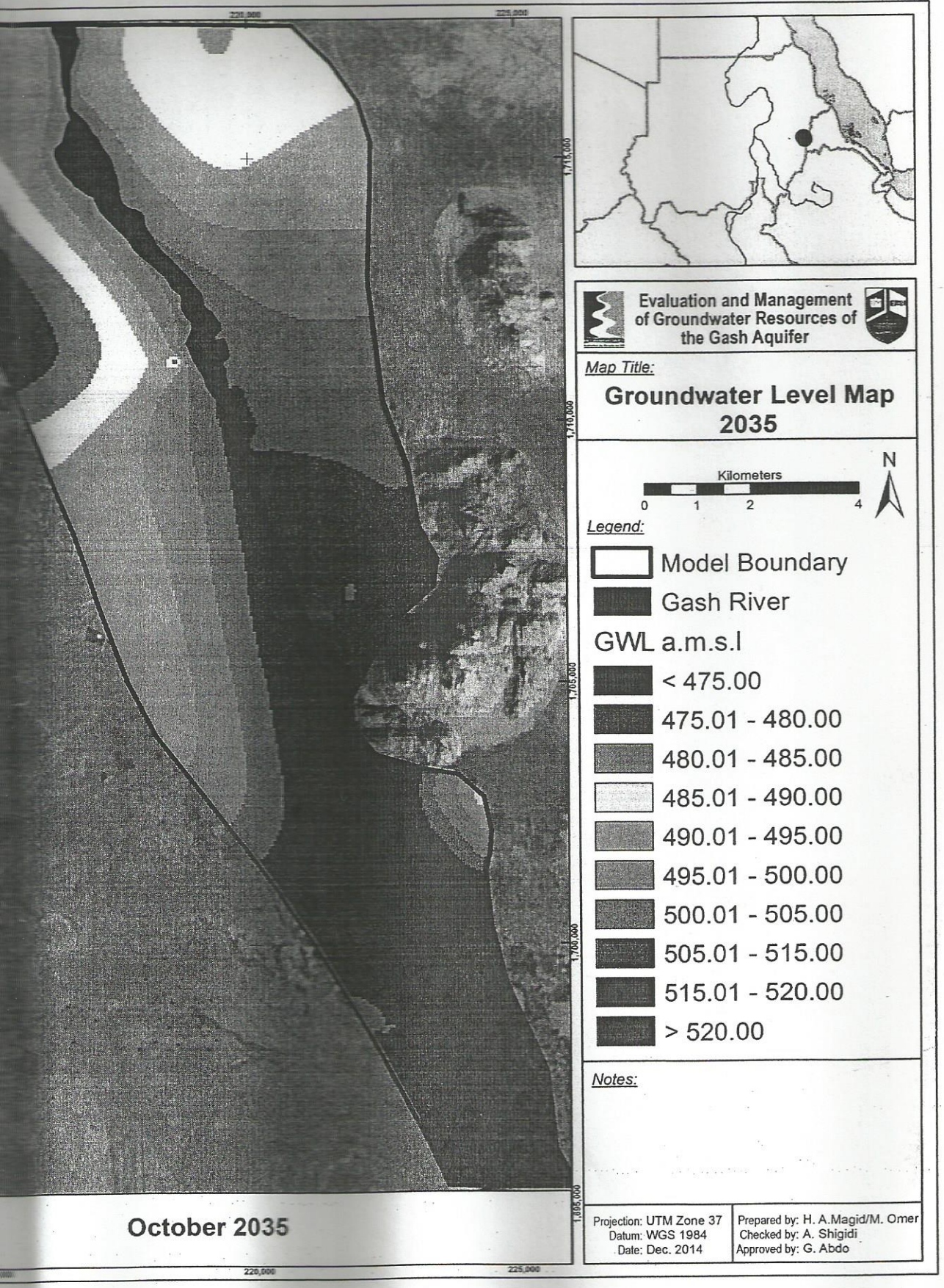


Figure 5-15: Groundwater



Level Map for Year 2030

Figure 5-16: Groun



Evaluation and Management of Groundwater Resources of the Gash Aquifer

Map Title:

Groundwater Level Map 2035

Kilometers

0 1 2 4

N

Legend:

- Model Boundary
- Gash River

GWL a.m.s.l

- < 475.00
- 475.01 - 480.00
- 480.01 - 485.00
- 485.01 - 490.00
- 490.01 - 495.00
- 495.01 - 500.00
- 500.01 - 505.00
- 505.01 - 515.00
- 515.01 - 520.00
- > 520.00

Notes:

Projection: UTM Zone 37 Datum: WGS 1984 Date: Dec. 2014	Prepared by: H. A.Magid/M. Omer Checked by: A. Shigidi Approved by: G. Abdo

Level Map for Year 2035

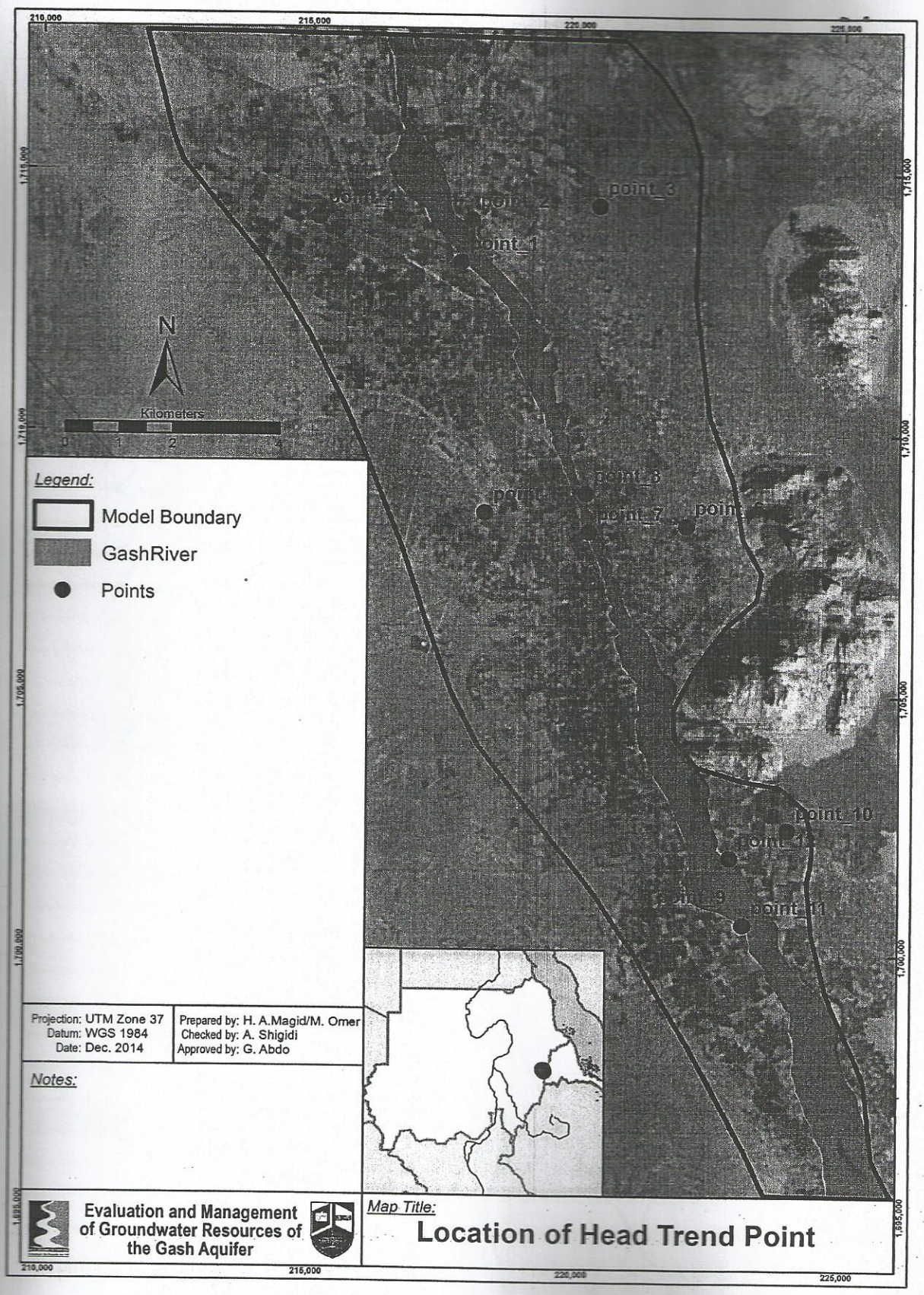


Figure 5-17: Location of Point Selected for Head Trend Variation Analysis

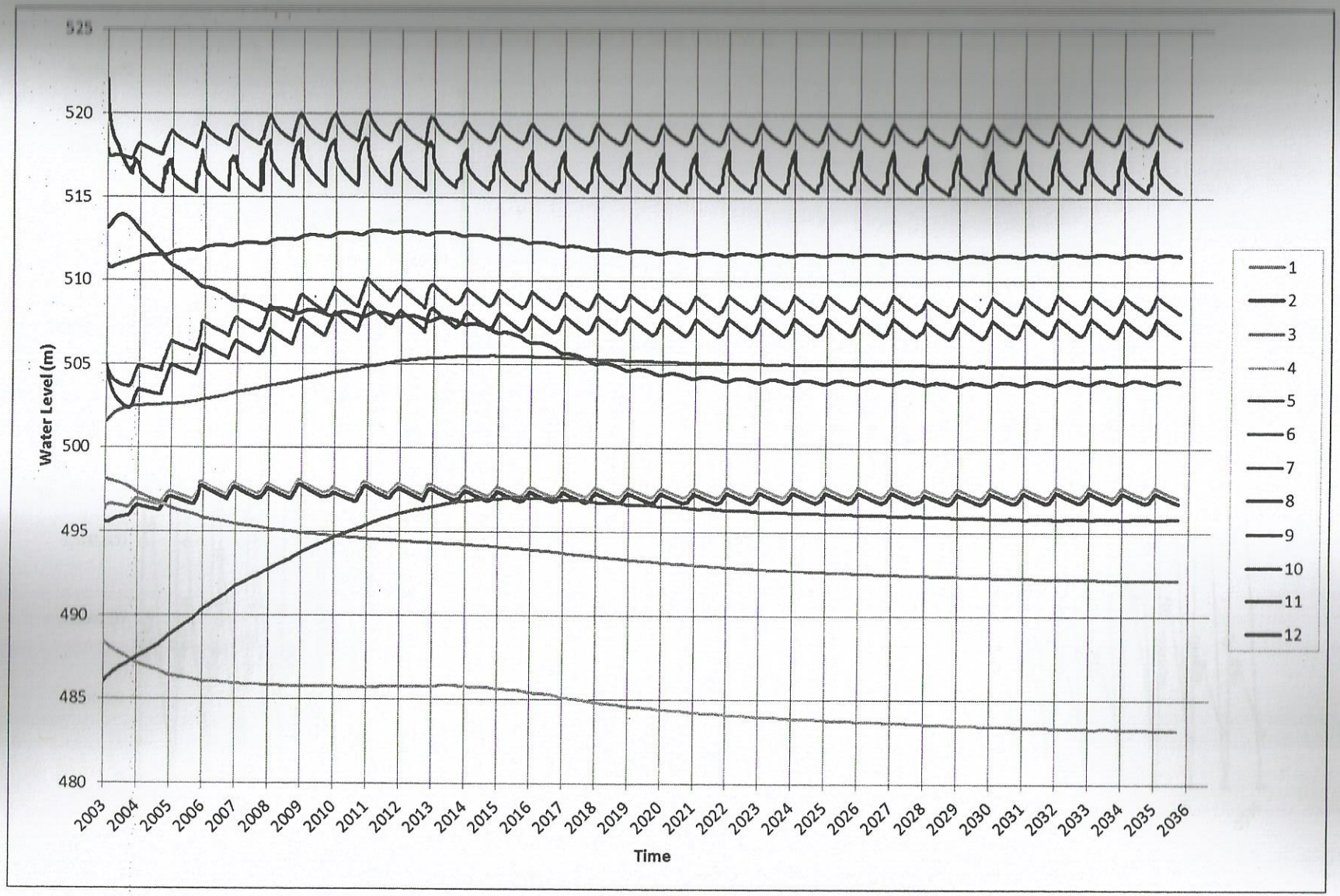


Figure 5-18: Groundwater Level Trends at Selected Points

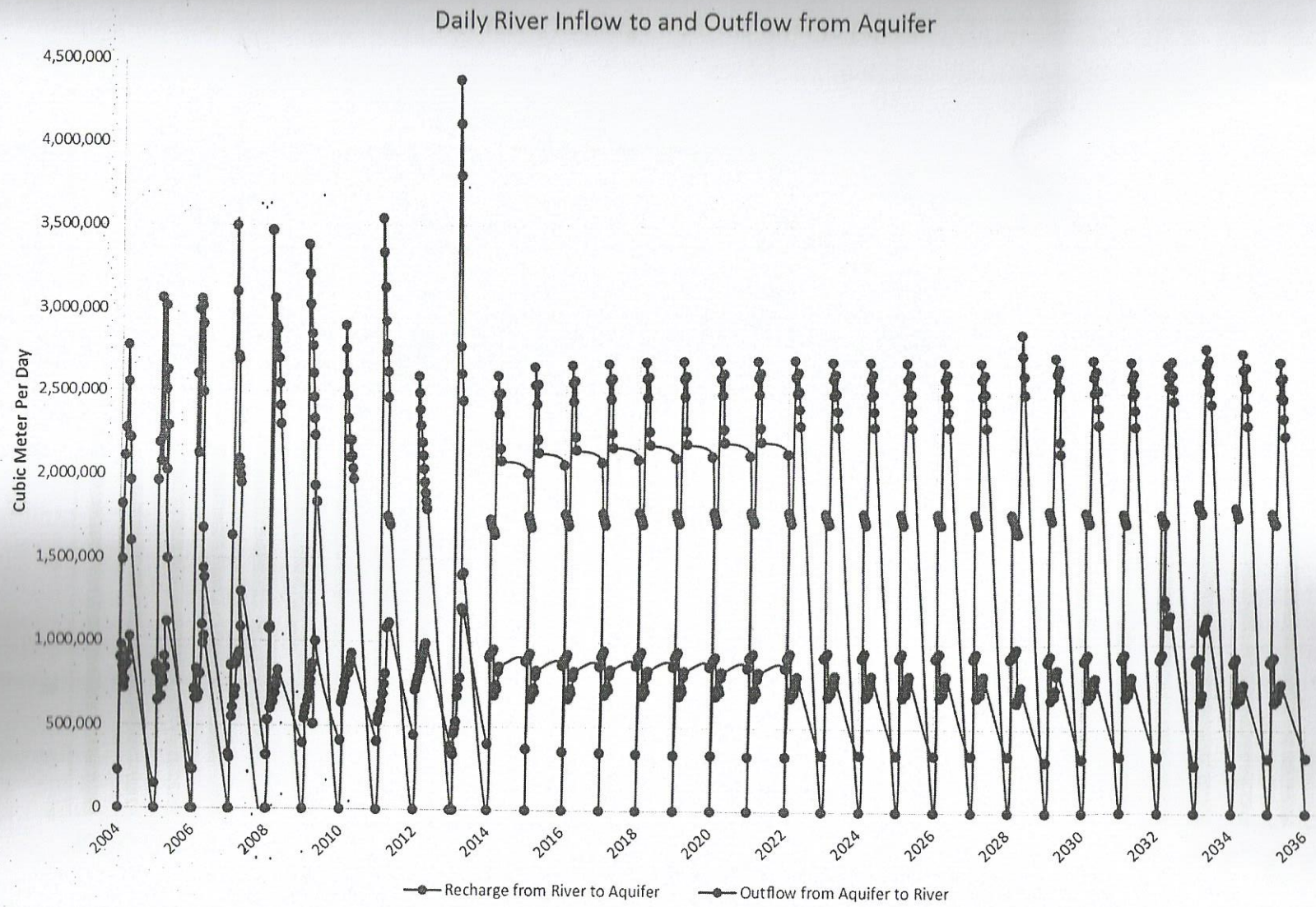


Figure 5-19: Daily River Recharge to the Aquifer and Outflow from The Aquifer to the River

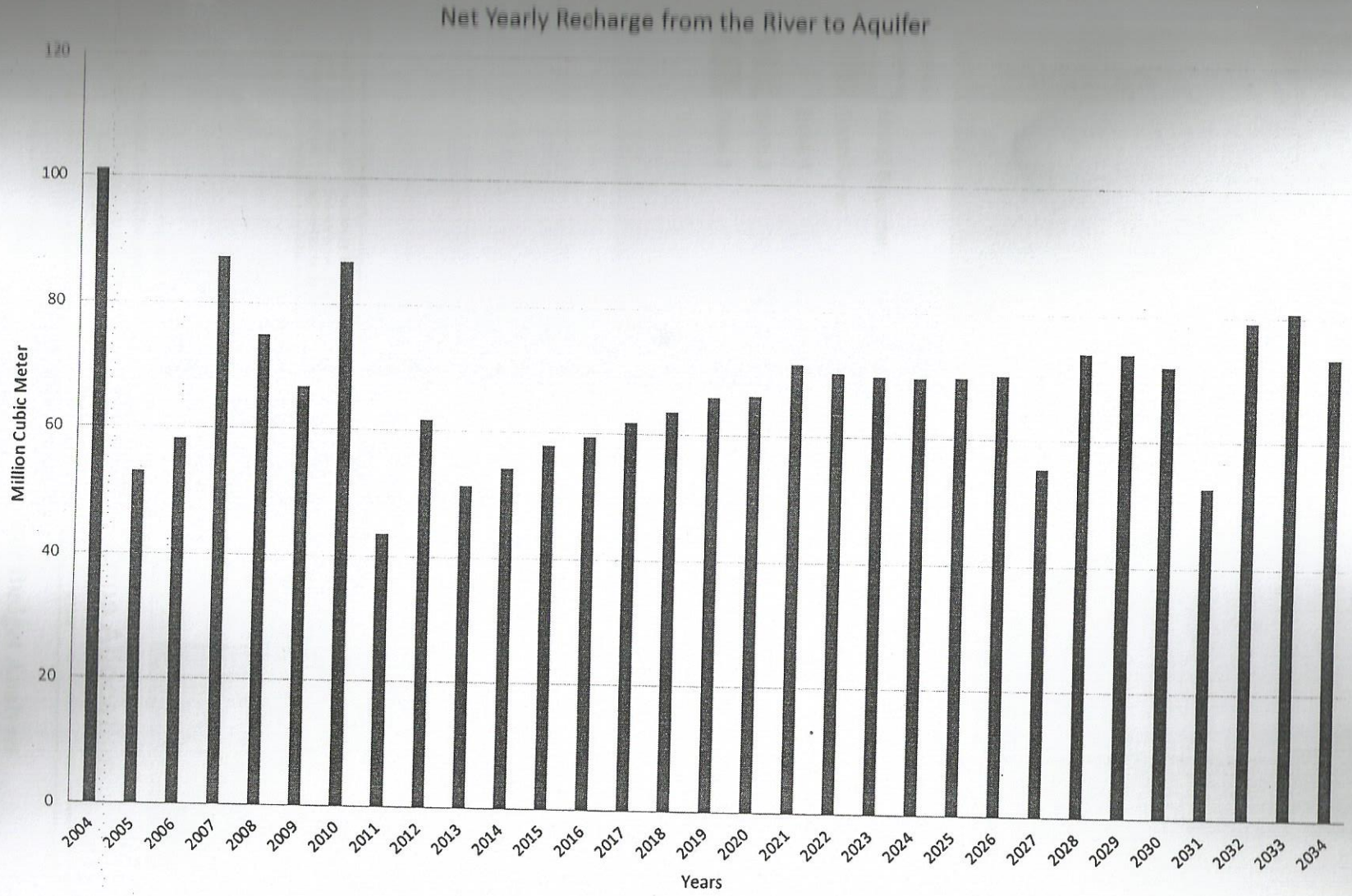


Figure 5-20: Annual Net River Recharge to the Gash Basin

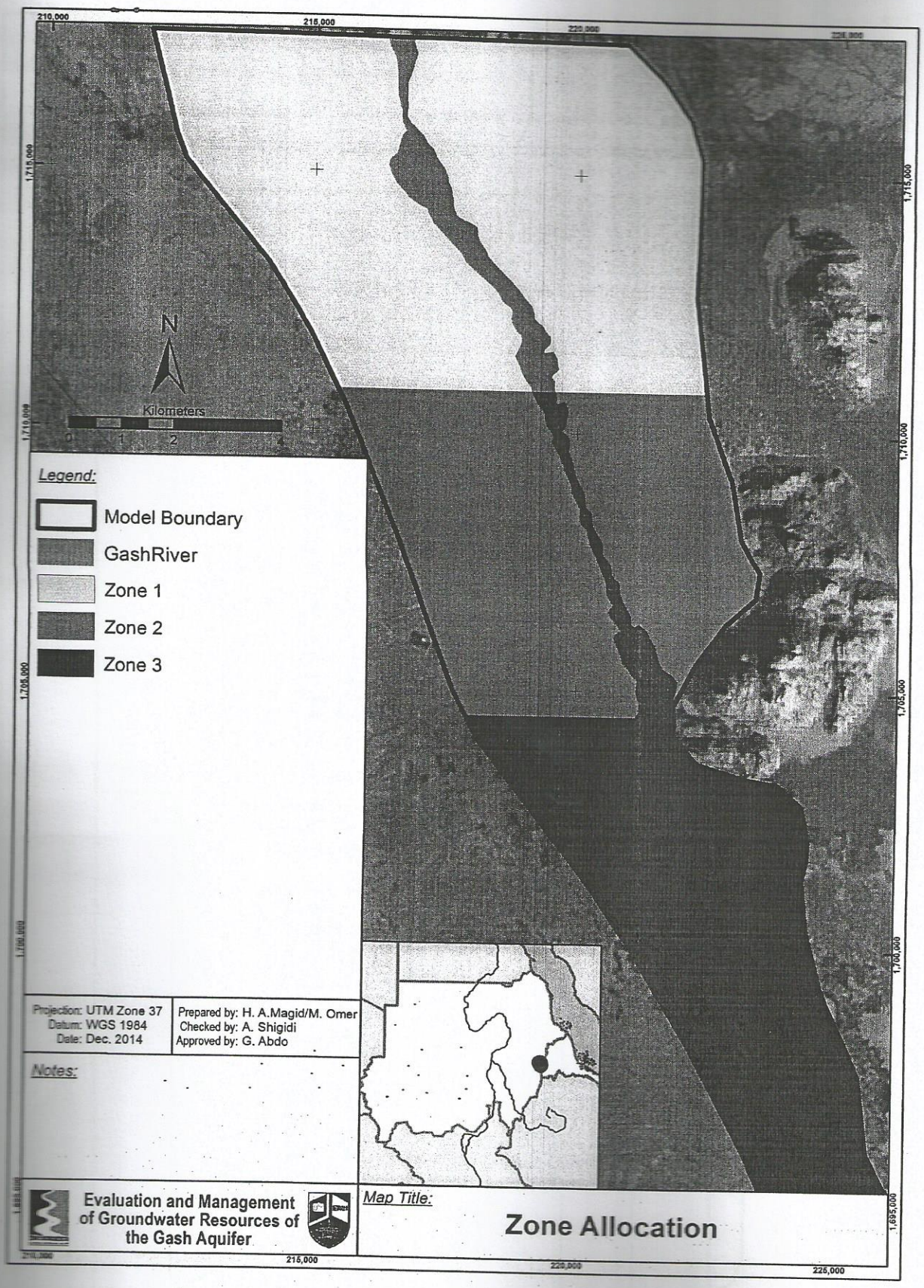


Figure 5-21: Zones for Water Budget Analysis

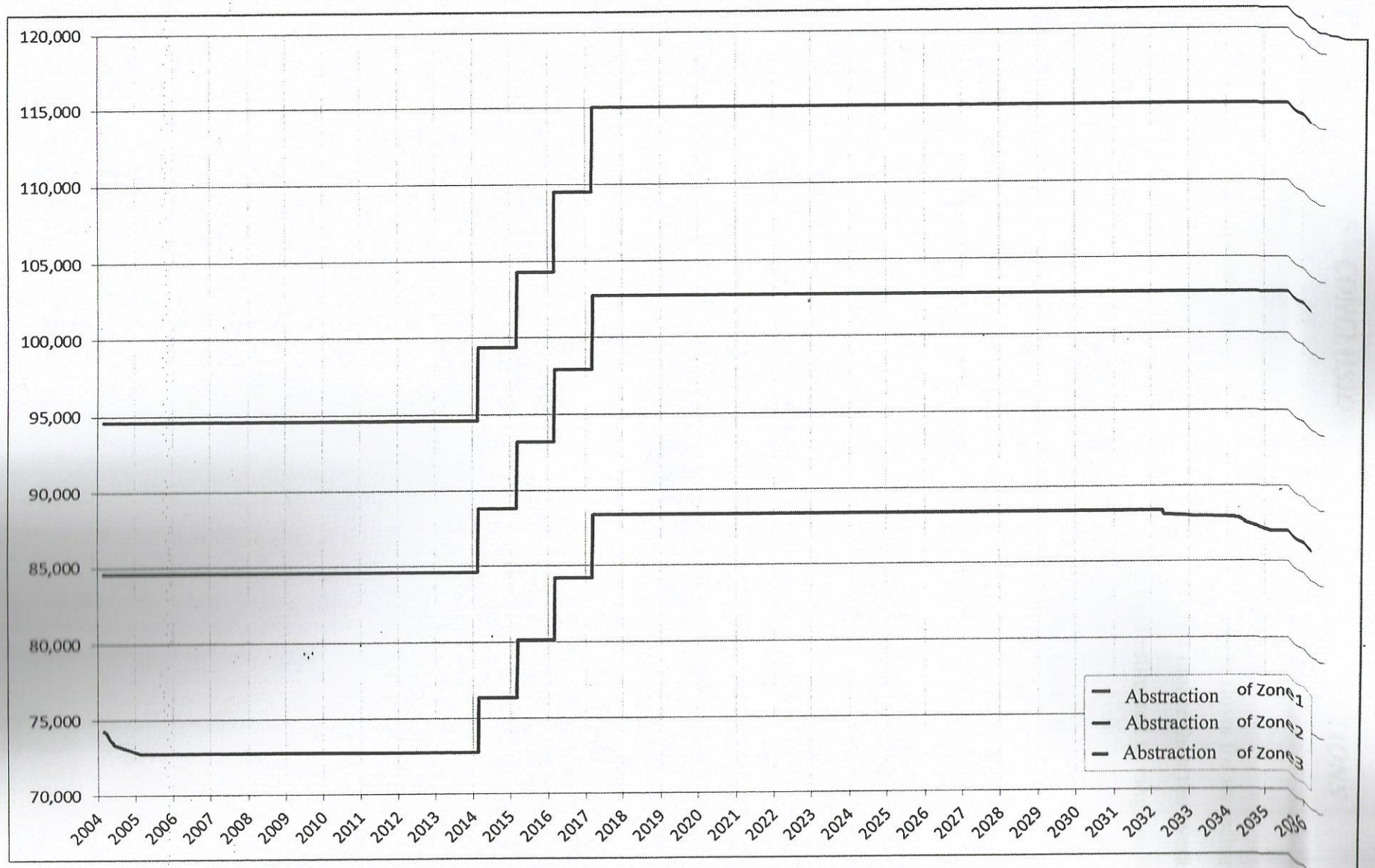


Figure 5-22: Daily Abstraction (m^3) from the Different Zones

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

- The Gash Basin relies almost exclusively on the Gash River flows for its recharge
- Current abstractions from the Gash Basin are about 20% higher than the average total annual recharge brought about by the Gash River Flood estimated to range between 45 and 101 MCM per year.
- Inspite of its shallow thickness the southern part the Gash Basin (south of Taka Mountain) plays a significant role in the recharge process of the aquifer as its receives most of the river inflow to the aquifer.
- The dry season currently experiences a cyclic reduction of groundwater levels of 2-5 meters compared to the rainy season.
- Long term impact of irrigation activities within the basin amount of 1-2.5 meter by 2020 and 2 – 5 meters by 2030 as compared to the year 2013.
- Care should be taken during the Gash river training efforts not to negatively impact the recharge potential of the Basin from the river, particularly in the southern section of the basin.
- The potential of the future expansion of horticultural development within the project area is very limited as it is likely to result in higher drawdowns.

6.2 Recommendations

The following recommendations are made for future improvements of the obtained results.

- The monitoring network of the Gash Basin has to be enhanced to cover basin area in its entirety.
- The accuracy and frequency of measurement of the ground monitoring systems must be enhanced to register at least one reading every month from each monitoring well for duration of one year.
- A better assessment of the current abstraction rates has to be conducted to generate a complete inventory of existing wells and the rate of production from each well.
- A stochastic analysis process is better suited to include the temporal variability of the Gash River flood when projecting future river floods.
- The exact location and the abstraction rates as well as the operational times for each of the existing domestic supply water wells are to be better identified.
- An accurate digital elevation model of the project area is required to eliminate the errors in computing the groundwater levels from depth to groundwater.

REFERENCES

1. ElKrail and Ibrahim (2008), Regional Ground Water Flow Modelling of Gash River Basin, Sudan, Journal of Applied Sciences in Environmental Sanitation, 3(3): 157-167.
2. Mukhtar (2009), Water Supply Situation and Future, Development Plans, Public Water Corporation.
3. Plan-Kassala (1998), Environmental Faults Study, Environment and Development Services.
4. Saeed (1972), Hydrogeology of Kassala District, Kassala Province, Ministry of Industry and Mining, Geological and Mineral Resources Department, Bulletin No.21.
5. TNO (1982), Water Resources Assessment Kassala Gash Basin, Ministry of Energy and Mining, National Administration for Water.

ANNEXES

Annex (1): Climatic Normals

SUDAN METEOROLOGICAL AUTHORITY

CLIMATOLOGICAL NORMALS 1981-2010

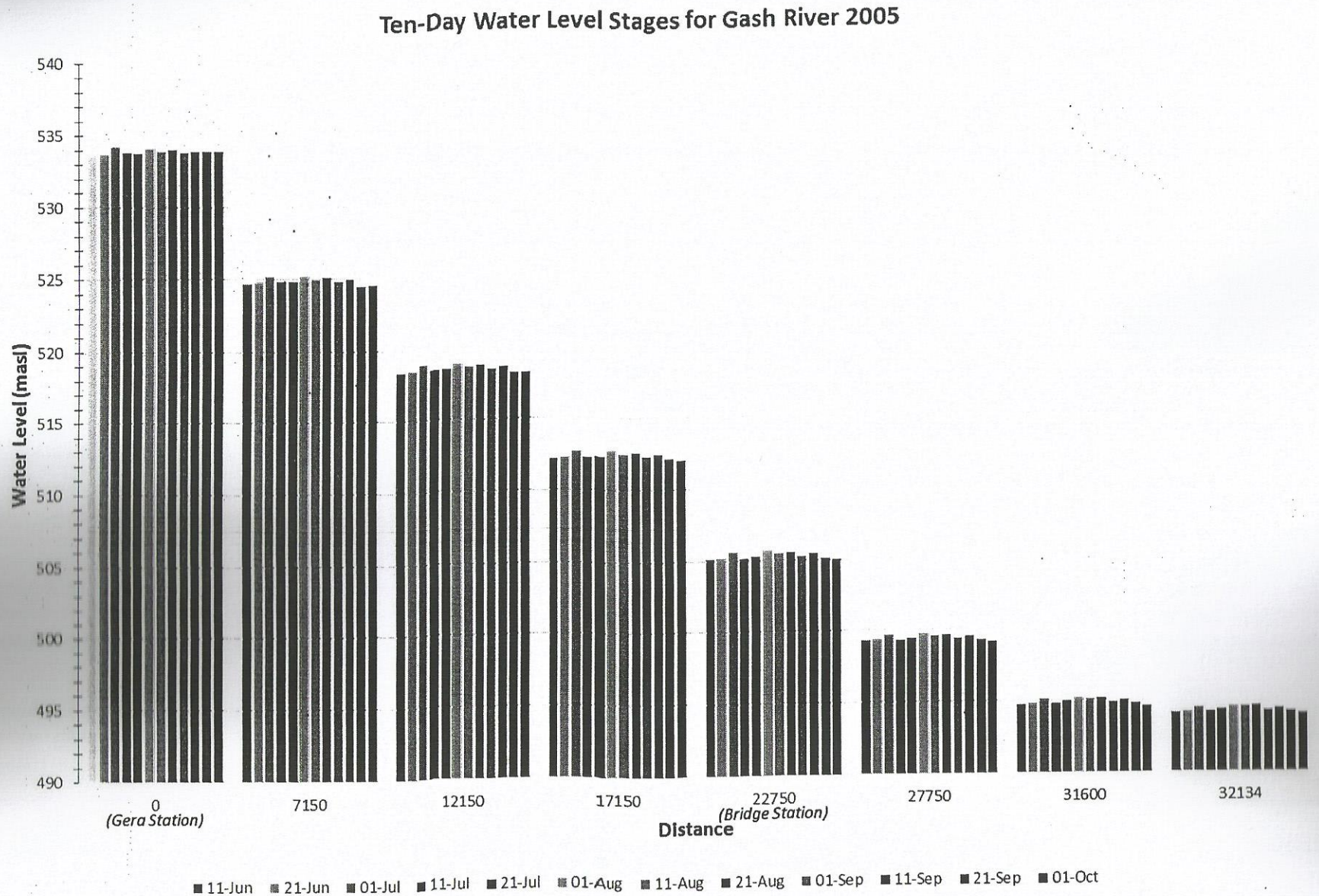
STATION: KASSALA LAT: 15° 28'N LONG: 36° 24'E ALT: 500 M

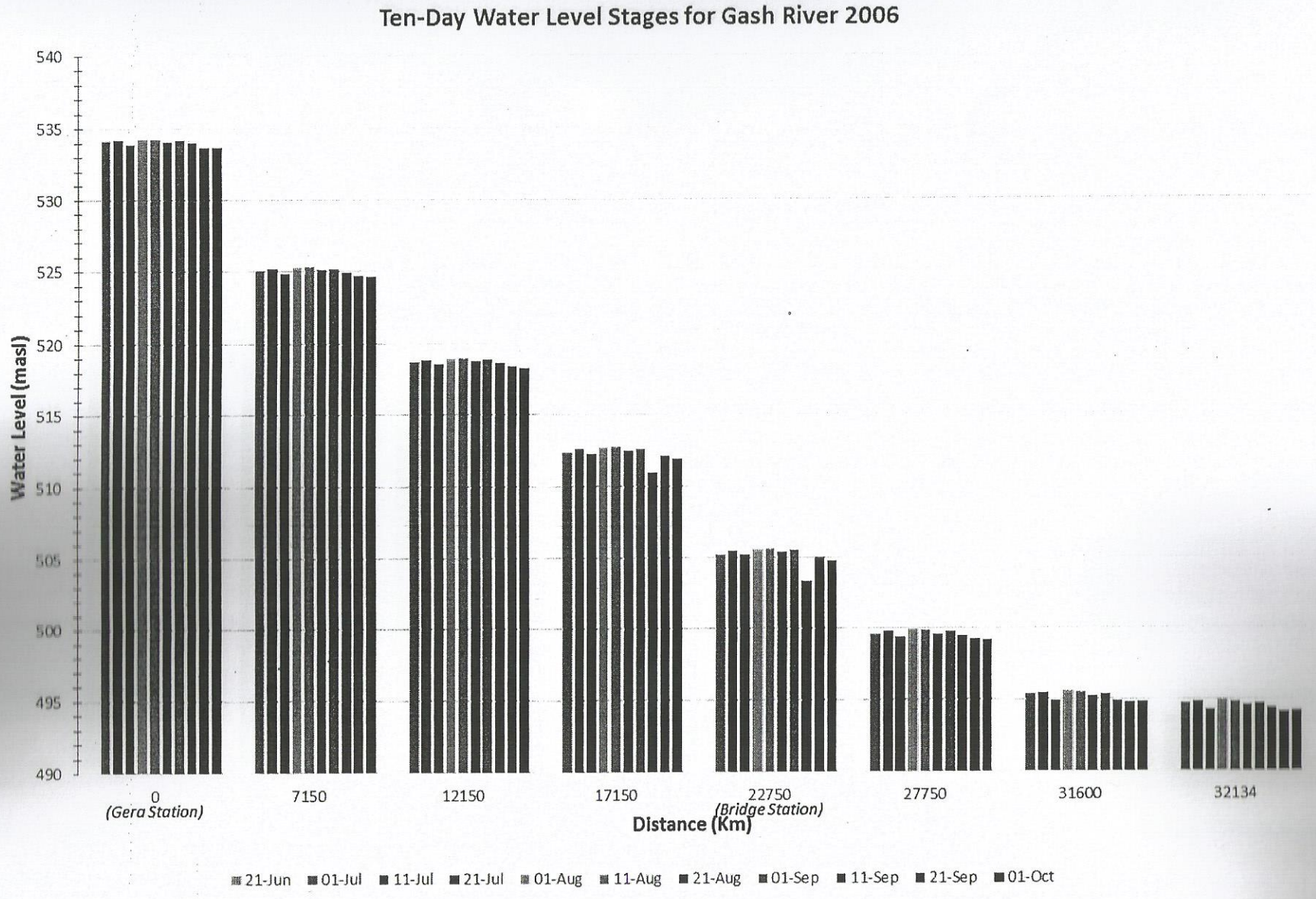
ITEM.	STAT. LEVEL PRESS	AIR TEMPERATURE						MEAN DRY TEMPERTURE (MAX+MIN)/2 IN °C	BRIGHT SUNSHINE DURATION	
		DAILY MAXIMUM			DAILY MINIMUM					
MONTH	HPA	MEAN	HST	DATE	MEAN	LST	DATE	IN °C	HRS	%
JAN.	954.6	33.7	40.7	25/26/1/2006	16.5	7.5	25/1/1983	25.1	10.0	87
FEB.	953.8	35.1	44.5	24/2/2002	17.7	5.0	02/06/1993	26.4	10.1	87
MAR.	951.9	38.0	44.6	30/3/1992	20.2	11.3	14/3/1982	29.1	10.0	82
APR.	950.3	40.9	46.5	04/11/1996	23.6	15.0	1/1981,4/2006	32.2	10.1	80
MAY	951.7	41.5	47.0	16/5/1990	26.2	17.9	05/11/1982	33.9	9.4	72
JUN.	952.4	40.0	44.8	06/01/1995	26.4	19.5	28/6/2007	33.2	9.2	72
JUL.	953.4	36.9	42.5	07/04/2002	24.7	17.8	07/12/1996	30.8	8.1	63
AUG.	954.1	35.4	41.6	25/8/1990	24.1	17.2	24/8/1999	29.7	8.2	66
SEP.	953.3	36.7	43.0	15/19/9/2009	24.4	18.3	23/9/1994	30.6	9.1	76
OCT.	953.5	38.6	42.0	SEV	24.8	19.0	10/08/1997	31.7	9.7	83
NOV.	953.2	37.4	41.0	11/2002,27/2009	22.4	11.5	26/11/1984	29.9	10.0	89
DEC.	954.3	35.1	40.2	12/07/1990	18.8	8.7	27/12/1983	26.9	10.0	89
YEAR	953.0	37.4	47.0	16/5/1990	22.5	5.0	02/06/1993	30.0	9.5	79

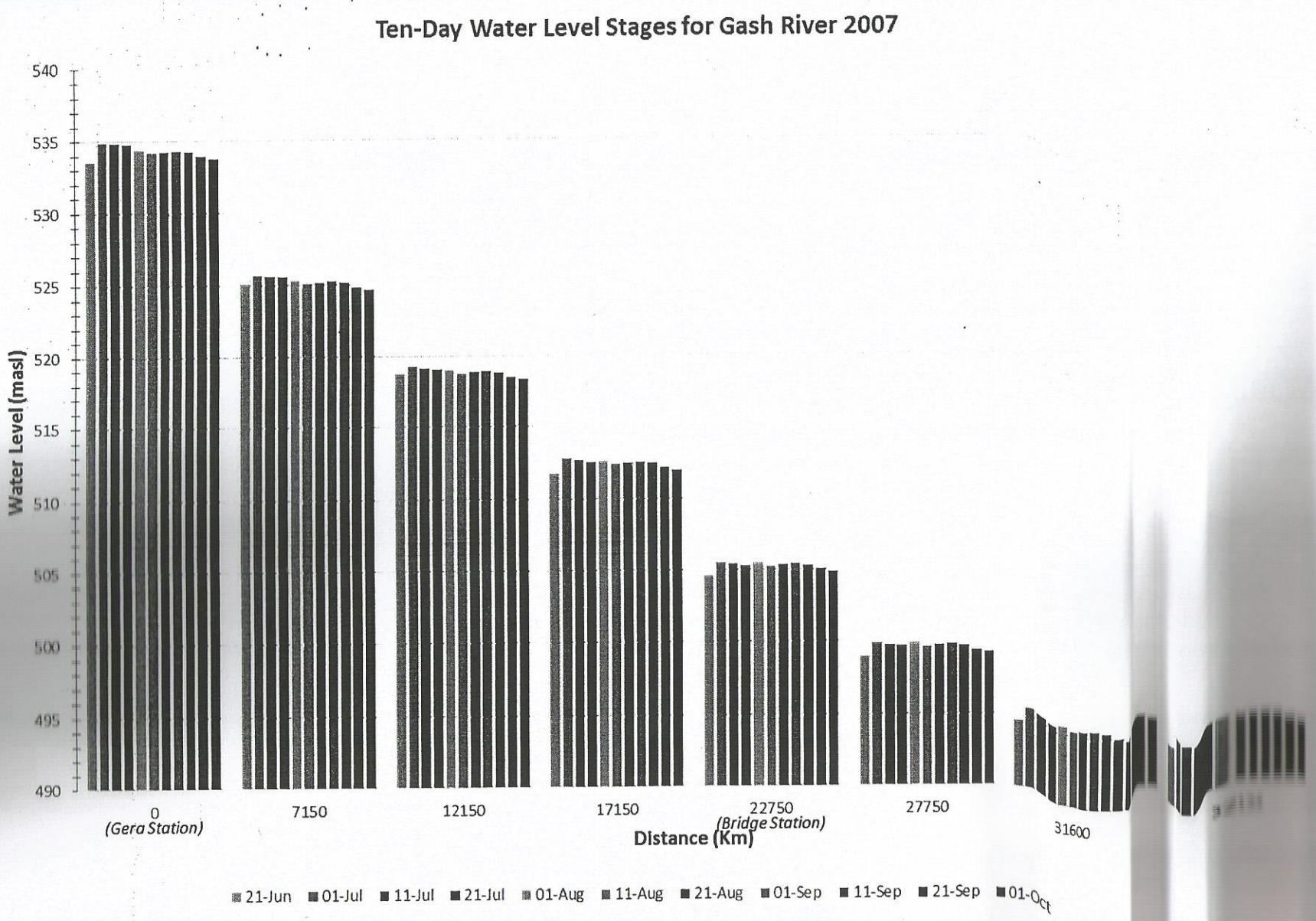
SUDAN METEOROLOGICAL AUTHORITY
CLIMATOLOGICAL NORMALS 1981--2010
STATION: KASSALA LAT: 15° 28'N LONG: 36° 24 E ALT: 500 M

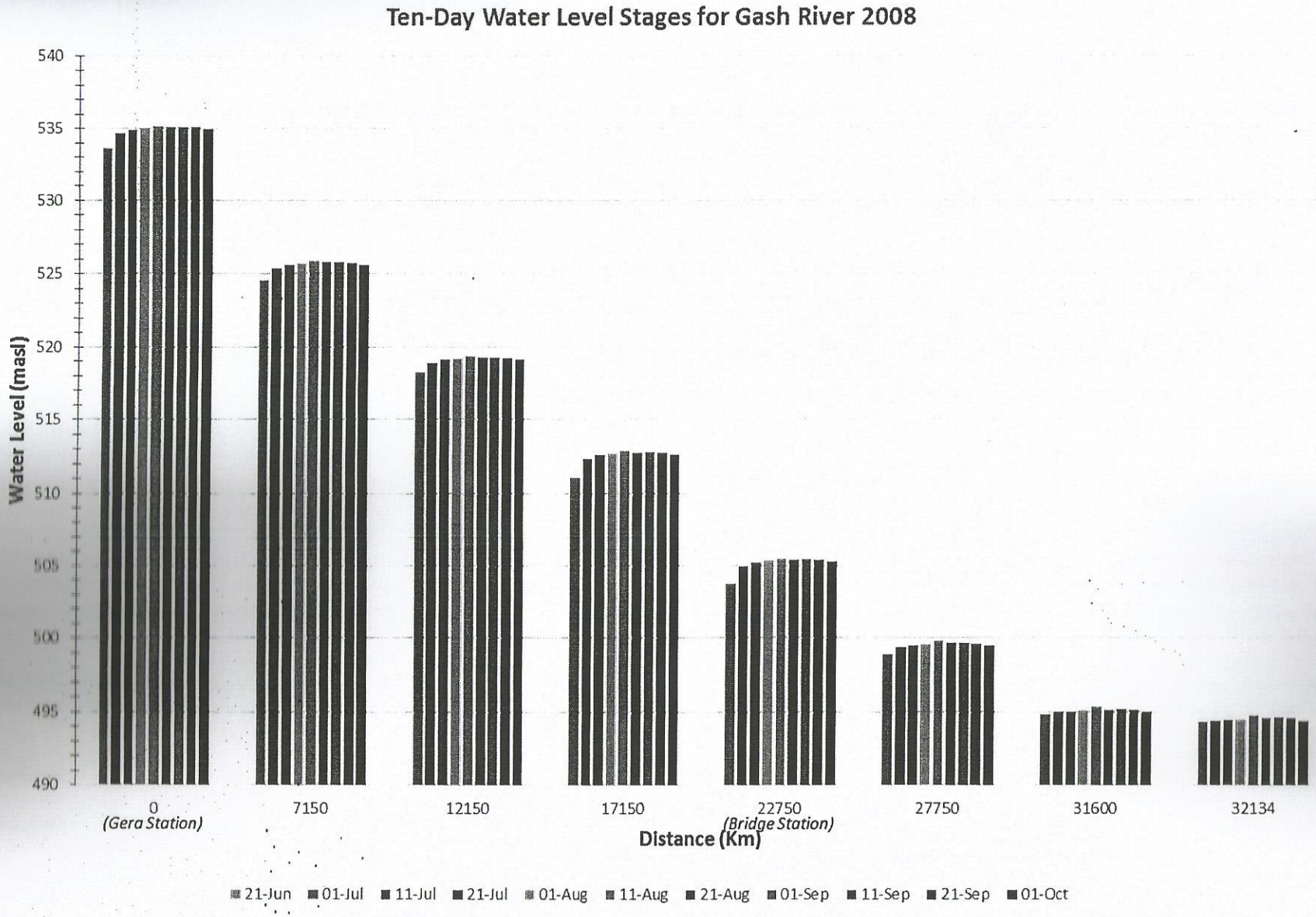
ELEM.	RELATIVE HUMIDITY R.H %	RAINFALL IN MMS						EVAP. PICHE (MM)	WIND	
		TOTAL IN MMS	NO. OF RAINY DAYS WHEN DAILY RAINFALL >=			MAXIMUM RAINFALL IN ONE DAY			PREV. DIR.	MEAN SPEED KM.P.H
MONTH	MEAN		0.1 MM	1.0 MM	10.0 MMS	TOTAL	DATE			
JAN.	45	0.0	0.0	0.0	0.0	0.0	---	10.8	N	9
FEB.	39	0.0	0.0	0.0	0.0	0.0	---	12.9	N	10
MAR.	31	0.0	0.1	0.0	0.0	0.3	25/3/1995	16.3	N	10
APR.	27	2.1	0.9	0.7	0.0	6.6	14/4/2000	18.2	N	9
MAY	30	11.0	2.3	2.1	0.2	30.5	05/04/1995	17.1	N	9
JUN.	38	24.4	2.3	2.0	0.5	145.4	27/6/2007	15.5	S	12
JUL.	54	67.6	6.6	5.5	2.0	83.2	17/7/2007	11.5	S	14
AUG.	60	81.9	7.8	6.7	2.6	90.0	24/8/1987	9.0	S	13
SEP.	53	39.2	3.8	3.2	1.2	57.0	09/05/1992	9.6	S	10
OCT.	40	8.6	1.4	1.1	0.2	52.0	10/01/1986	12.8	S	9
NOV.	39	0.2	0.1	0.1	0.0	5.6	11/01/1992	13.0	N	10
DEC.	45	0.0	0.0	0.0	0.0	0.0	---	11.1	N	11
YEAR	42	235.0	25.2	21.3	6.7	145.4	27/6/2007	13.1	---	10

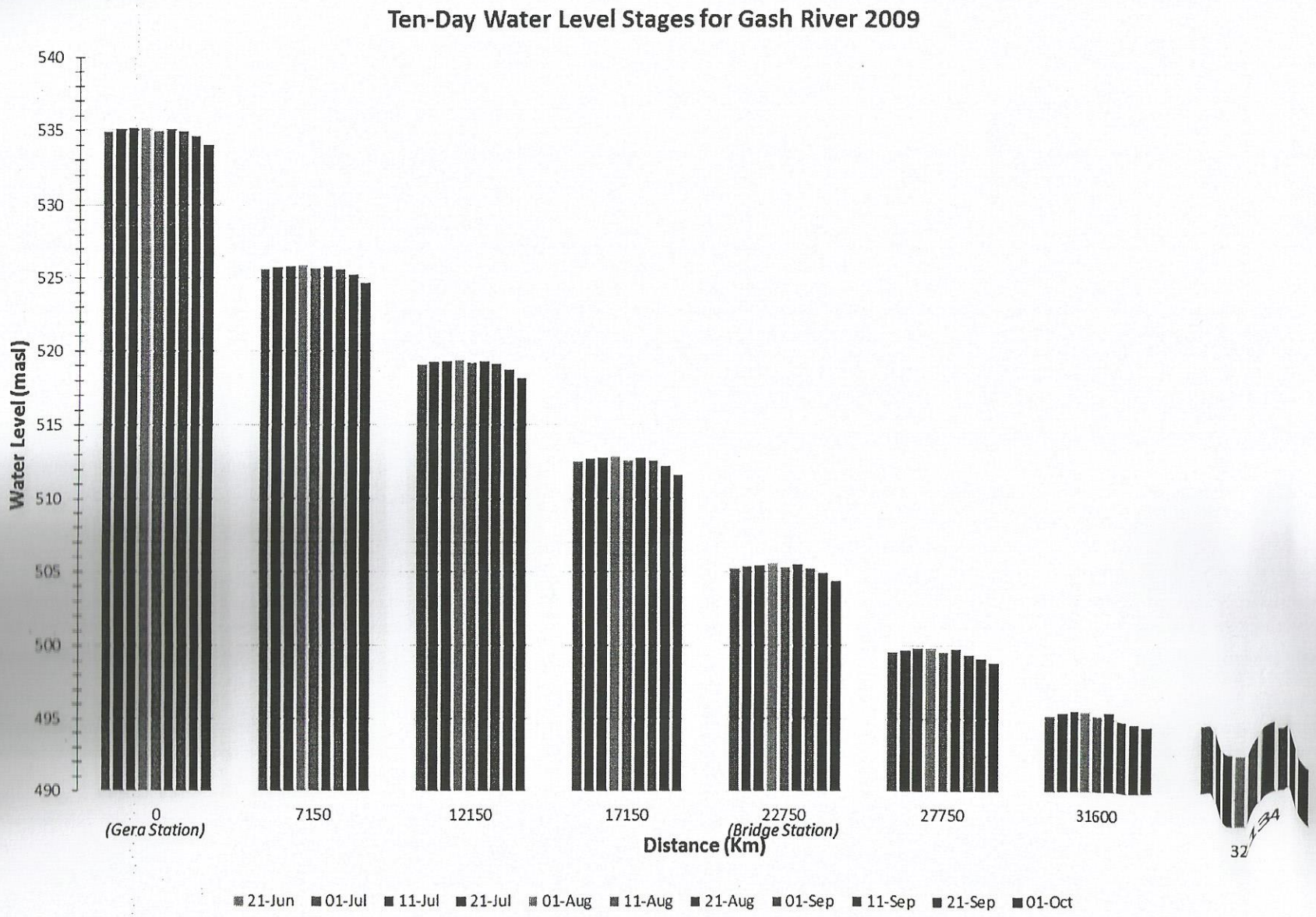
Annex (2): Gash River Stages (2005-2012)

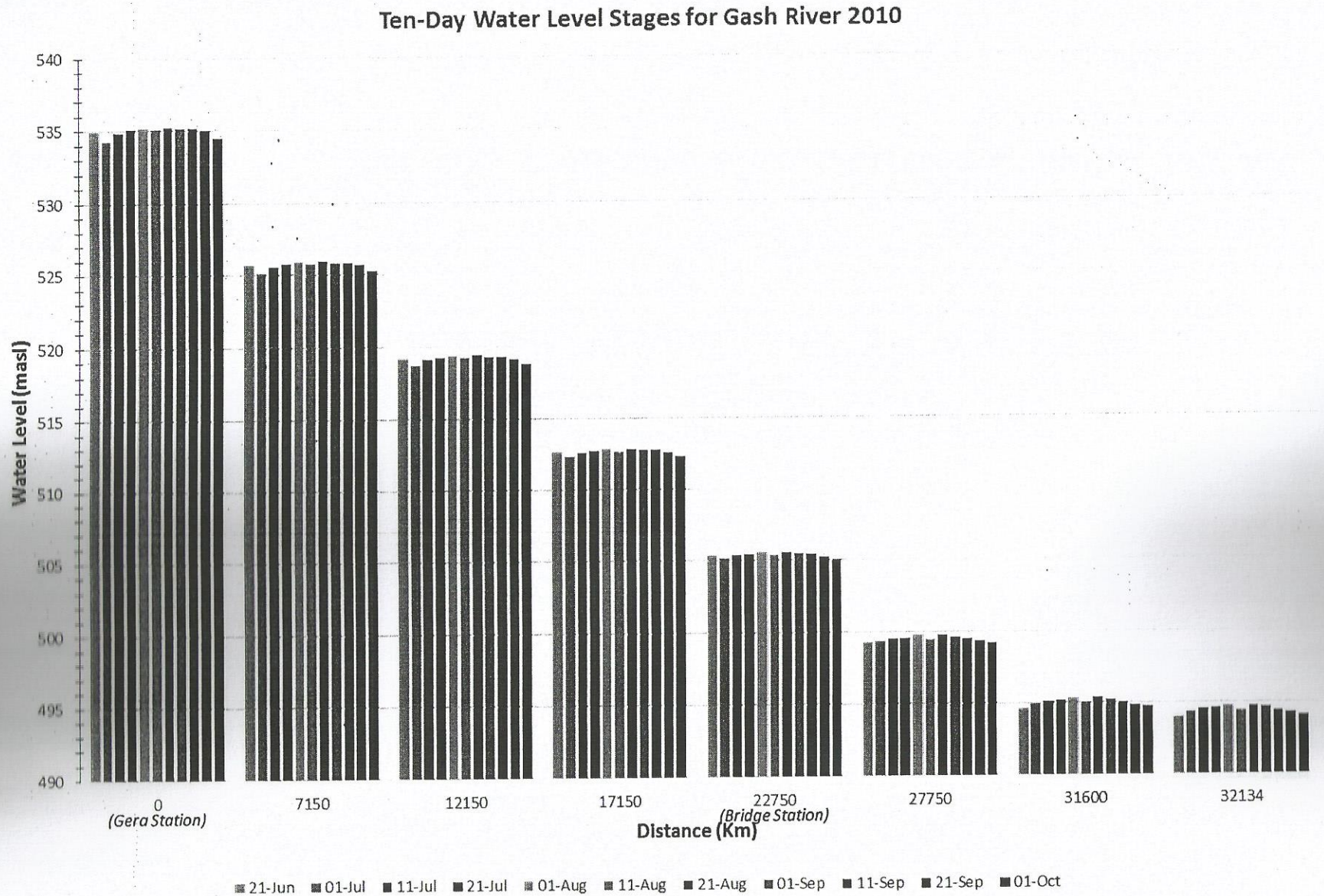

Ten-Day Water Level Stages for Gash River 2005
Water Level (masl)
540
535
530
525
520
515
510
505
500
495
490
0
(Gera Station)
7150
12150
17150
22750
(Bridge Station)
27750
31600
32134
Distance
11-Jun
21-Jun
01-Jul
11-Jul
21-Jul
01-Aug
11-Aug
21-Aug
01-Sep
11-Sep
21-Sep
01-Oct

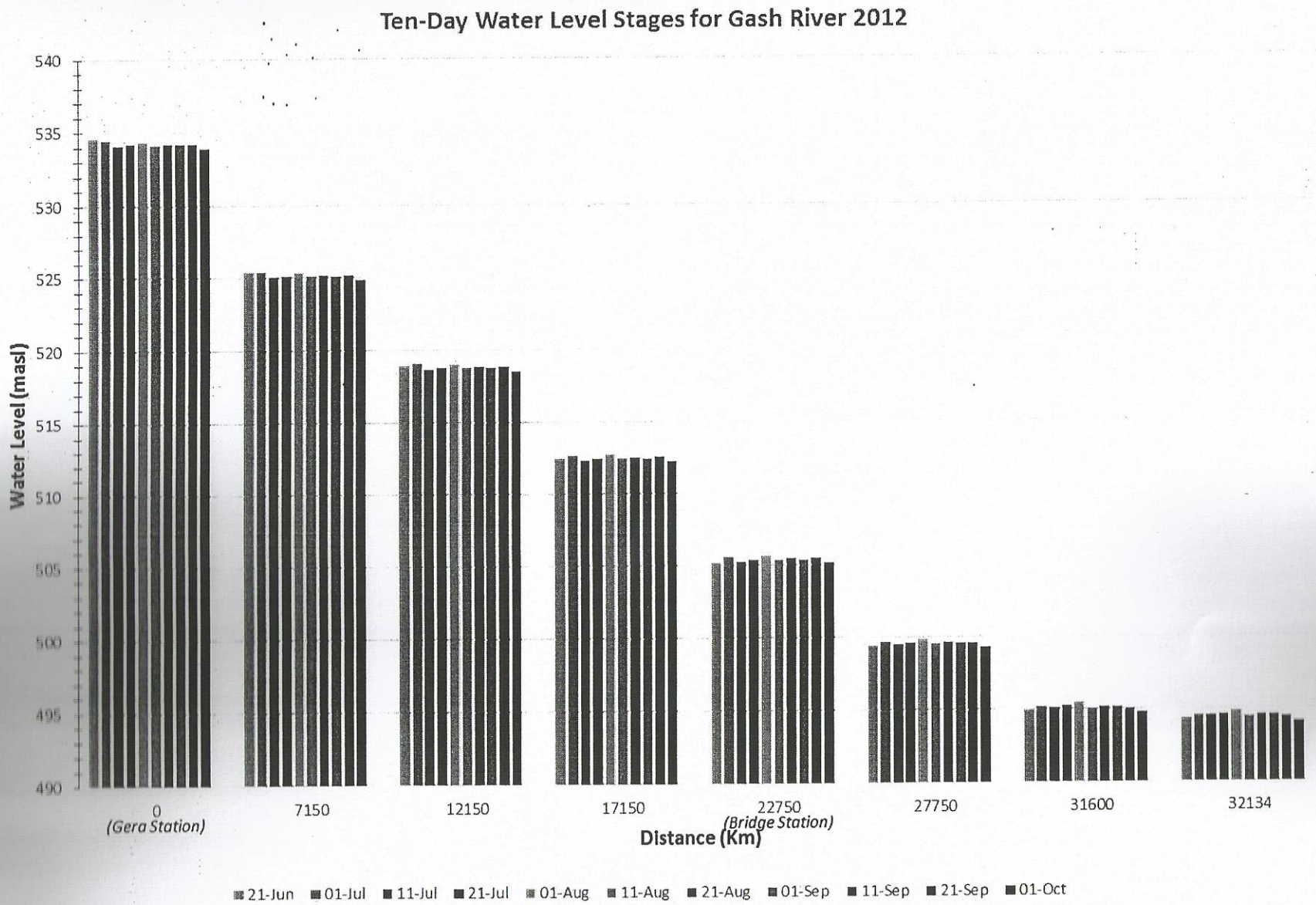

Ten-Day Water Level Stages for Gash River 2006
Water Level (masl)
540
535
530
525
520
515
510
505
500
495
490
0
(Gera Station)
7150
12150
17150
22750
(Bridge Station)
27750
31600
32134
Distance (Km)
21-Jun
01-Jul
11-Jul
21-Jul
01-Aug
11-Aug
21-Aug
01-Sep
11-Sep
21-Sep
01-Oct


Ten-Day Water Level Stages for Gash River 2007
Water Level (masl)
540
535
530
525
520
515
510
505
500
495
490
0
(Gera Station)
7150
12150
17150
22750
(Bridge Station)
27750
31600
Distance (Km)
21-Jun
01-Jul
11-Jul
21-Jul
01-Aug
11-Aug
21-Aug
01-Sep
11-Sep
21-Sep
01-Oct


Ten-Day Water Level Stages for Gash River 2008
Water Level (masl)
540
535
530
525
520
515
510
505
500
495
490
0
(Gera Station)
7150
12150
17150
22750
(Bridge Station)
27750
31600
32134
Distance (Km)
21-Jun
01-Jul
11-Jul
21-Jul
01-Aug
11-Aug
21-Aug
01-Sep
11-Sep
21-Sep
01-Oct


Ten-Day Water Level Stages for Gash River 2009
Water Level (masl)
540
535
530
525
520
515
510
505
500
495
490
0
(Gera Station)
7150
12150
17150
22750
(Bridge Station)
27750
31600
32
Distance (Km)
21-Jun
01-Jul
11-Jul
21-Jul
01-Aug
11-Aug
21-Aug
01-Sep
11-Sep
21-Sep
01-Oct


Ten-Day Water Level Stages for Gash River 2010
Water Level (masl)
540
535
530
525
520
515
510
505
500
495
490
0
(Gera Station)
7150
12150
17150
22750
(Bridge Station)
27750
31600
32134
Distance (Km)
21-Jun
01-Jul
11-Jul
21-Jul
01-Aug
11-Aug
21-Aug
01-Sep
11-Sep
21-Sep
01-Oct


Ten-Day Water Level Stages for Gash River 2012
Water Level (masl)
540
535
530
525
520
515
510
505
500
495
490
0
(Gera Station)
7150
12150
17150
22750
(Bridge Station)
27750
31600
32134
Distance (Km)
21-Jun
01-Jul
11-Jul
21-Jul
01-Aug
11-Aug
21-Aug
01-Sep
11-Sep
21-Sep
01-Oct

Annex (3): Simulated Groundwater Levels (2005 – 2035)