

SIMULATION OF WATER TABLE POSITION IN RESPONSE TO WEATHER AND TUBEWELL ABSTRACTION USING WASIM MODEL

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ABSTRACT

A study was conducted at Zabramari Fadama Area in Jere Local Government Area of Borno State, Nigeria. The area covers a fadama land of 1,700ha. The study was done to predict the behavior of the aquifer system for the purpose of sustainability. The WaSim software program which is a one dimensional processed based computer model was used to simulate the effect of water abstraction (irrigation) and weather (rainfall, evapotranspiration) under drained condition over a medium term period of ten (10) years. Soils, climate, crop and irrigation (abstraction) data were obtained from field study and used for the model validation. The data was analysed and results obtained displayed on the WaSim model interface. The findings showed that water table fluctuation ranged from 7.65 to 0.26 m for abstraction rate of 1.0 l/s to 6.5 l/s respectively. Maximum fall of water table over the period of simulation was 10.0m at an abstraction rate of 5.5 l/s. Climate had little effect on water table fluctuations (3.0m) for zero irrigation or zero abstraction. The effect of the average abstraction rate of 1.5 l/s over the study area was minimal (3.0m) on water table position (drawdown). Suction lift (8.0m) of portable petrol driven engine pumps used by farmers in the study area is below water table fall (3.0m) at abstraction rate below 5.5l/s which eliminate the fear of water table fall exceeding the suction lift of pumps. Suggestions and recommendations were proffered in relation to the establishment and maintenance of metrological station by State Government and Federal agencies for long term and accurate data.

Key Words: Simulation, Aquifer, Tube well, Abstraction and WaSim Model.

1 INTRODUCTION

1.1 General

One of the successful initiatives of the World Bank assisted Agricultural Development Programmes (ADPs) in Nigeria has been the small-scale low cost farmer-managed irrigation in the fadama [1]. This has contrasted with the large scale irrigation schemes developed by River Basin Development Authorities (RBDA's); which involves high capital cost and long period to bring land under irrigation [2].

Small scale fadama irrigation in Borno State has been identified as a key source of agricultural growth [3]. The usage of shallow aquifer is on the increase as a source of both domestic and agricultural water supply. Human activities such as dam construction have also resulted in draw down of groundwater table and piezometric levels downstream [4].

As the usage increases, there must be a tool for predicting the behavior of the aquifer system for the purpose of sustainability. Thus, modeling has become an indispensable tool for quantifying soil physical and chemical processes in the unsaturated and saturated zone as well as aquifer for fadama development [5], [6], [7], [8], [9], [10] and [11]. One of such model is groundwater model which can generally be used in the analysis of many groundwater problems [10], [11], and [12],

WaSim model, [10], [11], a one dimensional process based model (Water Balance Model) was thus used to simulate the water table in Zabramari Fadama area of Borno State. The model is multilayer that simulates soil water balance and water table under both drained and untrained environment, [10].

1.2 Extent and potentials of fadama in Borno state

Borno state has an area of about 69436km² with population of about 4.1 million, [13]. The ecology is fragile but notwithstanding, agriculture is the main stay of the economy. Economic returns from fadama development have been estimated to be over 30% [14]. Out of the total land area of Borno State, the irrigable fadama land is estimated to be about 550,000 hectare which is about 17.5% of the total fadama land in Nigeria [15]. The fadama covers the low land areas around the River Banks and the Lake Chad area which have high potentials for agricultural development under irrigation [15].

1.3 Problems of fadama development

Tube well/wash bores irrigation schemes where each farmer having his own water supply to irrigate 1 to 2 hectares of land to produce crops such as tomatoes and vegetables has been successful and very attractive. However, the question still remains; how sustainable is this development? [16] and [4]. There has been significant increase in fadama production and more tube wells and wash bores are sunk for irrigation. In spite of this, detailed studies to generate adequate data for planning and managing the fadama resources for sustainability has not been put in place [4]. Strategic plans have not been put in place to safe-guard over-exploitation. Monitoring wells were not constructed to monitor seasonal and annual fluctuation of groundwater levels. [17] and [18]. In the past two years, aquifer abstraction for domestic water supplies within the metropolis has more than doubled (personal communication with the residents within Maiduguri metropolitan city). These may constitute great problem to both medium and long term sustainability of fadama development in the state particularly that of Zabramari [17], [18] and [19].

1.4 Hydrogeology of the area

The Zabramari fadama consists of deltaic out wash deposit formed where the Ngadda and Goya Kyauwo River joined together and bridged the Bama ridge. The outwash deposit is complex due to repeated shifting of stream channels and inter fingering with coarse grained

materials [15]. The aquifer ranges from confined to unconfined depending on the thickness of the surface clay in relation to static water levels [15]. The fadama has good potentials for tube well development. Yields of 1 to 1.5 l/s are obtainable and static water level is about 4.5m [15].

Remnant drainage is apparent to far north-east of Leje. The recharge of the aquifer underlying the flood plain occurs through infiltration of water from the rivers [15]. The surface materials over most of the floodplains are clays and silts, which have low granular hydraulic conductivity. However desiccations and cracks are quite common in the clays. These openings also provide pathways for flood water to infiltrate downward to recharge the aquifer, [18].

1.5 WaSim model

WaSim is a process based model developed by [10]. The model carries out a one-dimensional daily soil water balance. It aims to simulate the soil water storage and rates of inputs (rainfall or irrigation) and output (evapotranspiration and drainage) of water in response to climate, irrigation and canal seepage where relevant as shown in Figure 1. The model also simulates changes in root zone soil water content and water table position in response to weather and water management practices (Figure 1).

It uses a five-layer soil water balance model to estimate the changes on a daily basis, taking into account input of rainfall or irrigation and output of evapotranspiration or drainage (modified for the crop cover and soil status and deep percolation, [10]. The deep percolation forms the input into water table model.

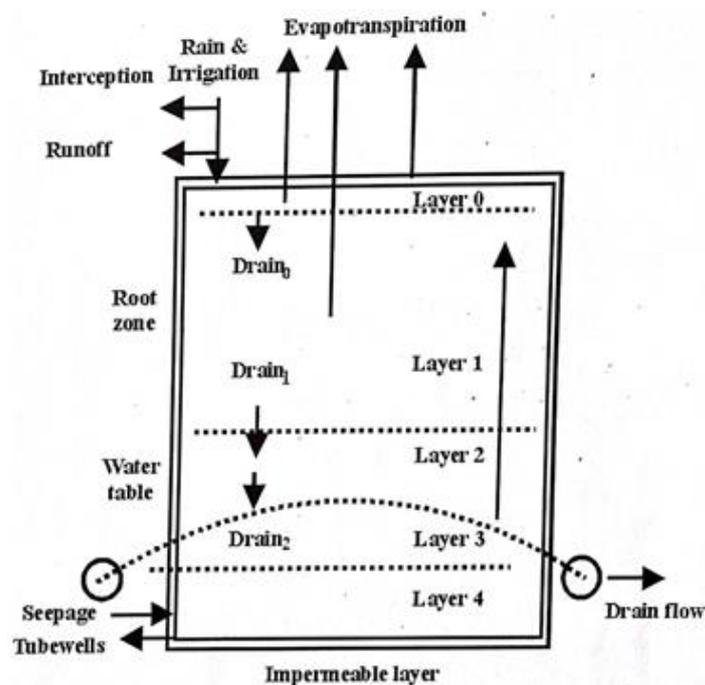


Figure 1. Overview of Wasim Model [10]

To run the model a time series of daily rainfall and reference evapotranspiration data are required. [10]. In addition to the crop and soil parameters, irrigation and drainage need to be defined. Wasim requires six sets of input data to simulate soil/water content redistribution.

These relate to the climate, soil, crop, irrigation, drainage and management practices. For the climate, the model requires daily rainfall and reference evapotranspiration, [10]. The minimum soil specific inputs are fraction of silt, clay and sand (soil type), soil infiltration, soil water content and hydraulic conductivity. For the crop, the major requirements are the sowing, maturity, harvesting dates and vegetative covers. The irrigation inputs data require scheduling rules and application rate while the drainage input requires drain diameter, drain spacing and depth. The management practices can be represented using the intervention menu on the animated display Figure 2 [10].

The model works through an animated graphical simulation of the crop growth, water balance output, water table position and salinity as shown in Figure 2. The output given in the model include, actual evapotranspiration, surface-run-off, soil water moisture in root zone, rainfall, irrigation, flow to drain and water table depth etc.

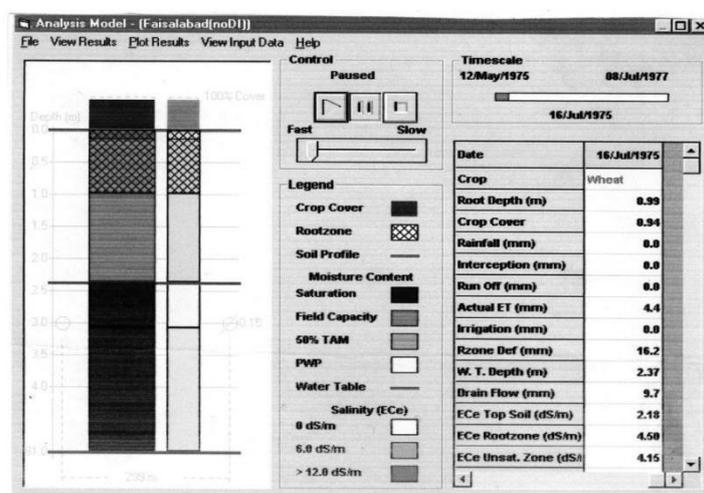


Figure 2. Overview of Wasim Model [10]

2 MATERIALS AND METHODOLOGY

2.1 Study Area

The study area selected is Zabramari fadama area in Jere local government area of Borno State. Zabramari is rated among the excellent fadama with high potential for development [15]. The area covers a fadama land of 1,700 ha, [20]. It is located north-east of Maiduguri between latitude $11^{\circ}40'$ and $12^{\circ}05'$ N and longitude $13^{\circ}05'$ and $13^{\circ}20'$ E.

2.2 Materials

Materials used for the study were laptops and mainly soil sampling equipment (Hand Auger and Soil Core Sampler), laboratory equipment (Balances, Ovens and conductivity apparatus), evaporation tank, piezometers, pumps and data obtained from metrological equipment of weather stations.

2.3 Methodology

Annual rainfall and reference evapotranspiration data were obtained for the year 1994 to 2003, from the metrological stations at Chad Basin Development Authority (CBDA), College of Agriculture Maiduguri, and Maiduguri International Airport. Climatic data were converted to ACS II type of climatic file data. The period selected for the simulation (10 years) corresponds to medium term simulation period. Soil physical data were carefully selected from literature and some from records of previous field studies. The soil input data used in running the computer based model was obtained from field survey report of the study area (Table 1). Soil, irrigation, climate and crop data of the study area were entered as input data (Tables 1, 2, 3 & 4). Assumption made include; one hectare was the area of abstraction over the period of simulation, depth to impermeable layer was 10m and pumping was 6 hours per week. Average abstraction rate over the area was 1.5l/s. Abstraction rate intervals used was 0.5 l/s.

Table 1 Soil Input data

Soil Name	Zabjere Fluvial
Soil Type	Silty Clay Loam
Saturation Point (%)	47.10
Field Capacity	35.00
Permanent Wilting Point (%)	20.80
Saturated Paste (%)	47.50
Hydraulic Conductivity (m/day)	0.036
Curve Number (USSCS)	50.00
Leaching Efficiency (%)	75.00

Table 2. Climatic Input data/run parameters

Parameter	Climatic data
Climatic File	C:\document and Settings/Admin
Station Description	Zabjere bowl. Maid.
Start Date	1/1/94
Finish Date	31/12/2003
Run	All dates in Climatic file (1/1/94 – 31/12/2003)

Table 3. Crop Input Data

Parameter	Crop data
Crop Name	Tomatoes
Crop Numbers	One (1)
Planting Date	30 th September
Planting Depth (m)	0.10
Emergence Date	Day 7 (06/Oct.)
20% Cover	Day 37 (05/Nov.)
Full Cover	Day 67 (05/Dec.)
Growth Period	Days 145
Harvest Date	21 st February
Max Root Date	Day 60 (28/Nov.)
Max Cover (%)	100
Multch Cover (%)	0.00
Full Cover (%)	100
Max Root Depth (m)	1.00
Adjustment for interception a, & b) $P_{eff} = a(p-b)$	0.00
P-Traction yield response	0.50
Salinity threshold / (ds/m)	1.70

Table 4. Irrigation/Tube well drain

Parameter	Irrigation	Tubewell Drain
Irrigation Plan Name	Washbore	-
Crop (I)	Tomatoes	-
Timing of Irrigation (Fixed Depletion % TAM)	25	-
Return to Fixed Depletion (% TAM)	25	-
Schedule date	30/Sept.	-
Finish date	07/Jan., Day 100	-
Drain diameter (m)	-	0.10
Depth of drain (m)	-	3.00
Spacing of Drain	-	35.00
Depth to impermeable layer (m)	-	10.00
Abstraction rate (L/S)	-	0.00 – 6.5 L/S

Simulation of the water table position in response to tube well abstraction was then carried out by varying the rate of tube well abstraction from 0.00 to 6.50 l/s. For the effect of climate on the water table position, the spatial variation of rainfall and the reference evapotranspiration were the key factors indicating the response over the ten-year period of simulation based on the following major processes in WaSim Model. They include; evaporation, transpiration, surface runoff, redistribution of soil water, drainage and losses from water table due to abstraction. The most important equation in built in the model are:

Evaporation

Open water evaporation occurs when the water table rises up to the soil surface and ponding occurs. In this case the soil is treated as open water evaporation loss and the rate is proportional to the reference evapotranspiration [14].

$$ET_{oi} = K_p E_{oi} \quad (1)$$

Where;

E_{oi} = open water evaporation on day i, mm.

ET_{oi} = reference evapotranspiration on day i, mm.

K_p = open water evaporation (pan) coefficient, dimensionless, 0.80.

Surface run-off

Surface runoff is comprised of two components; runoff due to intense rainfall (infiltration excess) and runoff due to saturated soil. As the rainfall data used to derive the water balance model is only available on a daily time step, daily surface runoff due to the intensity of rainfall R is estimated using the USSCS curve number method [15].

$$R_1 = \frac{(P - 0.28s)^2}{(P + 0.28s)} \quad (2)$$

Where;

R_1 = surface runoff mmd^{-1}

P = gross rainfall mmd^{-1}

s = maximum storage for the given antecedent conditions, mm.

Drainage

If the water fraction of any compartment is brought above saturation, any excess is assumed to be transferred to the compartment below it immediately by drainage. If the volume water fraction is between field capacity and saturation, then drainage released from compartment is calculated [10] as;

$$q = \tau (\theta - \theta_{fc}) (e^{(\theta - \theta_{fc})} - 1) / e^{\theta_{sat} - \theta_{fc}} - 1 \times 1000\text{mm/m} \quad [10] \text{ as; } \quad (3)$$

Where

q = drainage from compartment

τ = drainage constant dimensionless

θ = volume of water fraction dimensionless

θ_{fc} = volume of water fraction at field capacity, dimensionless

θ_{sat} = volume of water fraction at saturation, dimensionless

Losses from the water table due to tube well abstraction

Tube well abstraction (drainage) is assumed to extract water from the water table at a constant rate of 2.0 l/s for 6 hours pumping daily. The net flux from water table is calculated from the equation;

$$V_s = E_{gw} + T_{gw} + q_r - q - q_s \quad [14] \quad (4)$$

Where

V_s = Net flux from water table to root zone, mmd^{-1}

E_{gw} = contribution from water table to soil evaporation, mmd^{-1}

T_{gw} = contribution from water table to transpiration, mmd^{-1} .

q_r = daily extraction of tube well, mmd^{-1}

q = drainage from lower unsaturated compartment, mmd^{-1}

q_s = seepage from canal or river channel.

3 RESULTS AND DISCUSSION

3.1 Fluctuation of water table.

Maximum fall of water table of 10.00m was recorded between the months of July to August, while Minimum 2.86 m was recorded between October to December. The fluctuation of water table depth was moderate because during the raining season the aquifer is being recharged by the streams which probably balance the abstraction rate. Maximum water table fall was experienced throughout the raining season and minimum during the dry season because of the time it takes for the stream to be flooded and subsequent recharge of the aquifer. Another reason could also be attributed to the trends of evapotranspiration, which was maximum during the month of March/April and minimum during the month of December and January.

At zero abstraction rate (i.e. zero irrigation), the fluctuation of water table depth ranges from 2.86m to 3.0m (i.e. 0.14m difference), implying that effect of weather on water table position is minimum. Annual fluctuation of water table position for abstraction rate of 1.0 l/s to 6.5 l/s ranges from 3.0m to 10.0m over the period of simulation (i.e. 7.0m difference). This value indicates that there is much disparity between zero (0) and 6.5l/s abstraction and it could be inferred that the effect of tube well abstraction on water table position is significant.

At abstraction rate of 1.0l/s to 5.0l/s, the maximum water table fluctuation was 3.0m and minimum being 2.86m. This slight variation could be due to the low hydraulic conductivity (0.036 m/day) and drainage coefficient (0.09). Water table fluctuations at abstraction rate of 1 l/s to 5.0 l/s remain constant (ranging from 3.0m to 2.86m until at an abstraction rate of 5.5 l/s and above). At this abstraction rate, the rate of recharge balances up the abstraction. At an abstraction rate of 5.5 l/s to 6.5 l/s however, there was a drastic fall of water table, maximum being 10.0m and minimum 3.0m (Table 5). It could be concluded that rate of abstraction is higher than the rate of recharge during the drier periods.

Table 5. Water table depth position at various abstraction rates

File	Water table depth		Abstraction
	Max (m)	Min (m)	l/s
Jere SCL-TM.drr	3.00	2.86	0.00
Jere SCL-TM2.drr	3.00	2.86	1.00
Jere SCL-TM3.drr	3.00	2.86	1.50
Jere SCL-TM4.drr	3.00	2.86	2.00
Jere SCL-TM5.drr	3.00	2.86	2.50
Jere SCL-TM6.drr	3.00	2.86	3.00
Jere SCL-TM7.drr	3.00	2.86	3.50
Jere SCL-TM8.drr	3.00	2.86	4.00
Jere SCL-TM9.drr	3.00	2.86	4.50
Jere SCL-TM10.drr	3.00	2.86	5.00
Jere SCL-TM11.drr	10.00	3.01	5.50
Jere SCL-TM12.drr	10.00	3.01	6.00
Jere SCL-TM13.drr	10.00	3.01	6.50

NB. Irrigation at fixed depletion used was 50% total available moisture.

Table 6, shows the maximum, minimum, average and total values of some of the parameters from the annual summary of the result of simulation. The parameters include: root depth, crop cover, rainfall (mm), interception (mm), run off (mm), actual evapotranspiration ET (mm), irrigation (mm), root zone moisture deficit(mm), water table depth (m), and drain flow (mm).

Table 6. Annual Summary Data for various Parameters

Parameter	Max	Min	Ave	Total
Root Depth (m)	0.00	-1.00	-0.33	-
Crop Cover (%)	1.00	0.00	0.20	-
Rain Fall (mm)	98.50	0.00	1.80	6,469.10
Interception (mm)	0.00	0.00	0.00	0.00
Run off (mm)	23.60	0.00	0.10	201.90
Actual ET (mm)	16.10	0.00	3.50	13,081.80
Irrigation (mm)	16.00	0.00	2.10	7,913.10
Root Zone deficit (mm)	-32.40	143.50	24.10	-
Water Table Depth (mm)	10.00	2.86	9.09	-
Drain Flow (mm)	4.40	0.00	0.00	1,091.40

3.2 Maximum Rainfall/Runoffs

Maximum rainfall recorded over the period of simulation was 98.50 mm and minimum being 0, while average for the 10yr period was 1.80 mm. Total rainfalls over the period of simulation was 6469.0 mm. There was no interception since irrigation method adopted for the simulation was surface irrigation. Maximum runoff recorded was 2.36 mm and minimum 0. Total runoff recorded was 201.20 mm. The low runoff from the result of simulation was probably due to the soil type selected which is silty clay loam. This soil type has a moderate infiltration capacity. Low runoff result could also be attributed to the moderate to low rainfall recorded over the years.

3.3 Actual ET/Irrigation

Table 3 also indicate that maximum actual evapotranspiration (ET_o) was 16.10mm while minimum was 0. Average actual ET_o was 3.50mm, and total actual ET_o over the period of simulation was 13081.80mm which is high. This could be due to the high evapotranspiration and solar radiation during greater part of the year. The high evapotranspiration could also be attributed to the principles of Richies equation (2) which consider evaporation in two parts namely moisture and energy dependent.

Maximum irrigation was 16.00 and minimum being 0, while average irrigation over the period of simulation was 2.10mm and total was 7913.10mm (Table 3.2). The moderate value could be because water abstracted was applied back as irrigation at fixed depletion of 25% total availed moisture (TAM).

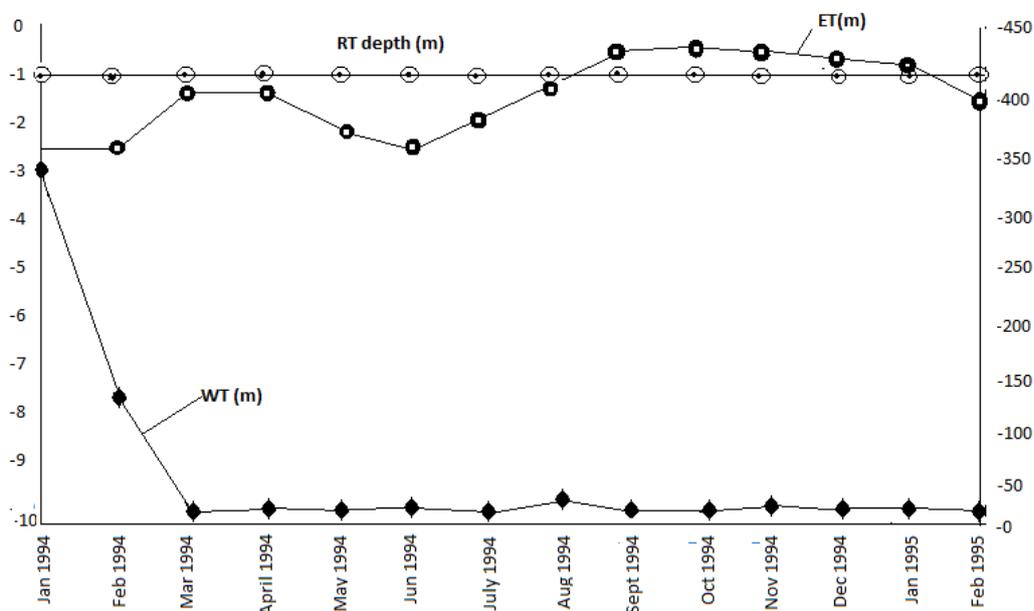


Figure 3. Water Table and Actual Evapotranspiration (ET) and monthly fluctuation.

Actual ET_o peak recorded as indicated by the graphs was 445.0mm and monthly ET_o ranges from 5.0mm to 445.0mm (Figure 3). These high values are as a result of high solar radiation as stated earlier.

3.4 Drain flow

The drain flow was low, 4.40mm maximum and total 1,091.40 mm. The total value of drain flow was not high due to the fact that drainage used in the simulation (tube well abstraction) was not the conventional pipe drainage but wash bore where water is taken directly from the aquifer and applied as irrigation directly there by returning certain quantity back into the aquifer. Figure 3 shows graphical representation of the water table fluctuation and actual evapotranspiration and root depth while Table 7 a summary of the fluctuation of water table over the simulation period for abstraction rate of zero (0), (1.5l/s) and (6.5l/s). For abstraction rate of 0.0l/s to 5.0l/s the fluctuation was constant between 3.0mm to 2.86 mm.

The result shows that for abstraction rate of zero (0) the monthly water table fluctuation on the graph is almost a straight line while that of 1.0l/s is regular in shape with slight drop at certain intervals. This also remains constant. For the graph of abstraction rate of 5.5l/s to 6.5l/s the graph has a sharp drop from 3m to 9.9m and flattens at 10.0m. This sharp drop was explained in section 3.1 (abstraction rate being higher than recharge). Table 7 shows the summary of the simulation over the whole period from 1st January 1994 to December 2003. The summary of all the parameters and the values of abstraction rates of 0.00 l/s, 1.5 l/s and 6.5 l/s is comprehensively summarized in Table 7.

Table 7. Summary of result data (01/Jan/1994 – 31/Dec/2003)

Parameters	Zero (0) Abstraction				Abstraction 1.5l/s				Abstraction 6.5l/s			
	Max	Min	Ave	Total	Max	Min	Ave	Total	Max	Min	Ave	Total
Water Table (m)	3.0	2.9	3.0	-	3.0	2.9	3.0	-	10.0	3.0	9.1	-
ET (mm)	16.1	0.0	3.5	12900.2	16.1	0.0	3.5	12,900.2	16.1	0.0	3.6	13081.8
Rainfall (mm)	98.5	0.0	1.8	6,469.1	98.5	0.0	1.8	6,469.1	98.5	0.0	1.8	6469.1
Root depth (m)	0.0	1.0	0.3	-	0.0	1.0	0.3	-	0.0	1.0	0.3	-
Crop Cover (%)	1.0	0.0	0.2	-	1.0	0.0	0.2	-	1.0	0.0	0.2	-
Run off (mm)	23.6	0.0	0.1	201.9	23.6	0.0	0.1	201.9	23.6	0.0	0.1	201.9
Interception (mm)	3.0	0.0	0.0	5.7	3.0	0.0	0.0	5.70	16.0	0.0	0.0	5.7
Drain Flow (mm)	4.4	0.0	0.0	-	4.4	0.0	0.0	1,091.4	0.0	0.0	0.0	0.0
Irrigation (mm)	16.0	0.0	2.1	7,685.8	16.0	0.0	2.1	7,685.8	16.0	0.0	2.2	7913.1
Root Zone deficit (mm)	-32.4	143.5	24.1	-	-32.4	143.5	24.1	-	-32.4	143.5	34.2	-
Water content in G/W	3,273.5	3,273.5	3,273.3	-	3,273.5	3,273.5	3,273.3	-	3273.5	0.0	427.3	-
Water content in Topsoil	69.0	28.0	47.4	-	69.0	28.0	47.4	-	69.0	28.0	47.5	-
Water content in Root	285.2	0.0	69.1	-	285.2	0.0	69.1	-	285.2	0.0	68.9	-

4 CONCLUSION

The results of simulation of water table position indicates that it does not fall below suction lift (8.0m) of the petrol driven engine pumps used by farmers in the study area at an abstraction rate below 5.5 l/s. Maximum water table fall was 10.0 m at an abstraction rate of 6.5 l/s. This is far above the average abstraction rate of 1.5 l/s where water table fall was

3.0m. As long as abstraction rate does not exceed 5.5 l/s long term Fadama irrigation farming is sustainable provided the aquifers are recharged by the streams. The results also indicate that climate has little effect on water table fluctuation at zero irrigation (zero abstraction rates). Maximum, minimum, average and total values for water table fluctuation from the annual summary of the simulation are within safe limits hence sustainability could be maintained. It could be concluded therefore that from the medium term simulation period (10years) sustainability of small scale irrigation farming in the Fadama could be maintained and farmers conveniently can continue to use the portable petrol driven engine pumps.

5 RECOMMENDATIONS

It is recommended that long term simulation period (30years) should be carried out using other models (e.g. mudflow and GSM 9.5 model) to further subject the study of water table fluctuation through simulation in the study area under various water management practices to ascertain long term sustainability. Secondly, it is also recommended that State Government and Federal Government agencies should establish more network of Metrological station for long term adequate and accurate data collection. Lastly, it is recommended that farmers should continue to use the petrol driven engine pumps of 8.0m suction lift and not change to other pumps that has higher suction lift for sustainability.

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