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MODELLING GROUNDWATER FLOW OF THE BESEASE INLAND VALLEY BOTTOM IN GHANA

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Abstract

The harsh climate, shallow and erodible soils of low fertility uplands have led to farmers extending their cultivable areas to wetlands for optimal crop production since these systems have the potential for irrigation in the dry season. Inland valleys have been cited as having high potential for development of rice-based, small-holder farming systems at the village level, due to their specific hydrological conditions and relatively high soil fertility. This paper applies a 3D groundwater flow model, PM-WIN MODFLOW to simulate the groundwater heights of the two layered alluvial aquifer of the Besease Inland Valley Bottom. Groundwater recharge estimates from the watertable fluctuation method was used as the recharge input into the model. The results showed that groundwater levels ranged from 259.10-259.97 m in the wet season and 258.19 -258.86 m in the dry season for the simulation period. It also exhibited a form of interaction between the inland valley wetland and the bordering Oda River which varied over time depending on the river stage. The values for storage from the model were substantial and indicated the temporal variability in the watertable with continuous movement of water to and from storage over an annual cycle. Sensitivity analysis was performed, and model outputs were found to be highly sensitive to the catchment parameters such as horizontal hydraulic conductivity, specific yield and specific storage. The model helps to unravel the relationship between recurrent spatial and temporal patterns of watertable response within the inland valley bottom and their controlling factors.

***Keywords**:* Wetlands, MODFLOW, Groundwater, Model, Crop Production.

Introduction

Farmers along the Oda River in Ejisu-Besease in the Ashanti Region of Ghana practice floodplain cultivation as a form of supplementary irrigation. The Government of Ghana through the Agricultural Sector Rehabilitation Programme of the Ministry of Food and Agriculture (MOFA) and the Crops Research Institute (CRI) are actively encouraging floodplain cultivation, which can be practiced in the dry season using pumped water as a source of irrigation. Groundwater is of prime importance to the meet rapidly expanding urban and agricultural demands. In analyzing groundwater systems, information about the fluctuation of the storage component of the wet and dry season floodplain wetland needs to be quantified in a water budget at a variety of spatial and temporal scales. Determining wetland hydrology is therefore important for understanding how the wetland system functions and for predicting its response to natural (e.g. climatic) and imposed (e.g. management) climatic change (Krasnostein and Oldham, 2004). The most common approach for determining wetland hydrological processes is to calculate the water balance on all sources and sinks to the system. Groundwater modelling has emerged as the best tool to conceptualize the hydrogeological situation in a groundwater basin (Himmelsbach and Buter, 2001) and to predict the groundwater resources (Walton, 1970). Models used for determining wetland hydrology can be classified as physical and mathematical models. Mathematical models are divided into analytical and numerical models. There are some numerical models available to predict groundwater flow and these can potentially be used to generate the input data required to closed wetland water balance (Krasnostein and Oldham, 2004). In numerical models, the finite difference and finite element methods are used for solving groundwater equations. The finite difference method is a frequently used technique for solving groundwater problems. The reliability of prediction using a groundwater model depends on how well the model approximate field situations (Anderson and Woesnner, 1992). Groundwater flow models like MODFLOW, a physically based numerical groundwater flow model, has been applied in many aspects of wetland hydrology research because it can represent a wide range of drainage situations, geometry, configurations and different hydraulic settings. MODFLOW has been used to predict watertable behaviour in several wetland modelling studies. This paper focuses on the simulation of groundwater flow system at the Besease inland valley using groundwater flow modelling. The aquifer system was modelled using PMWIN (Chiang and Kinzelbach, 2001) assuming steady and transient state conditions. The recharge to the underlying aquifer is due to infiltration from the Oda River during flood seasons or direct precipitation from rainfall. The watertable fluctuation method was employed to estimate the recharge. Indeed shortage of rainfall in the dry season in the study area causes a marginal reduction in the groundwater height which has lessened the productivity of the small holder farmers at the inland valley. This paper develops a numerical model to assess the irrigation potential of the wetland for crop production. It also simulates an optimum groundwater hydraulic head to determine an adequate irrigation depth for maximum crop yield as well as quantification of the water balance of the area.

Study Area

Besease is a predominant farming area in the Ejisu Municipal District of the Ashanti Region in Ghana. The site lies within Latitude 1º 15¹ N and 1º 45¹ N and Longitude 6º15¹ W and 7º 00¹ W. The study area covers about 72 ha of the valley bottom lands at Besease (Figure 1). The climate of the study area is mostly related to the semi-humid type. The region is characterised with two distinct seasons, the wet season which begins from April and ends in October while the dry season extends from the month of November-March. The wet seasons can be categorised under two rainy seasons. The major rainy season which ranges from mid-March to July and the minor rainy season starts from September to mid-November. The mean annual rainfall is 1420 mm; mean monthly temperature is 26.5°C, the relative humidity ranges from 64% in January to 84% in August. The average monthly maximum and minimum evapotranspiration (ET_o) for the study area are 127.5 mm and 64.7 mm and has a an annual ET_o of 1230 mm. The area is drained by the Oda River which is seasonal and whose basin is about 143 km² (Kankam-Yeboah *et al*, 1997).

The study area is located in the moist semi-deciduous forest zone. Grass species prominently found in the valley bottom are *Santrocema trifolia, Chromolaeve ordorata, Imperata cylindrical, Mimosa pigra,Ceiba patendra, Centrosema pubescens and Mariscus flabelliformis*. Plant species like *Raphia hookeri (Raphia palm), Alstonia boonei, Malotus oppositifolius and Pseudospondias microcarpa* extends along the margins of the Oda River. Soils of the Ejisu-Besease can be found in the soil map of Kumasi area. The study area lies in the Offin soil series which are grey to light brownish grey, poorly drained alluvial sands and clays developed within nearly flat but narrow valley bottoms along streams. The series have very slow internal drainage, very slow runoff, rapid permeability and moderate water holding capacity. The geology of the watershed is relatively heterogeneous and mainly composed of Phyllites, quartzite, shale, Tarkwaian and Voltaian-sandstone and limestone. The Phyllites which underlie 59 % of the area consist of upper and lower Birimian rocks. Very few rock outcrops were encountered in the survey as the rocks are deeply weathered. The weathered phyllite is soft and easily broken, recognizable pieces and is typically found at 2-3 m below surface. Soils found within the Oda River catchment are grouped as those derived from granites, sandstones, alluvial materials, greenstone, andesite, schist and amphibolities. Specifically the soils are Orthi-ferric Acrisol, Eutric Fluvisol, Gleyic Arenosols, Eutric Gleysols and Dystri-Haplic Nitisol. The Besease aquifer is composed of heterogeneous sequence of layers which is dominated by sand, clayey sand and silts. The valley bottom is developed by small holder farmers who cultivate rice in the wet season and also grow vegetables like cabbage, lettuce, sweet pepper, cauliflower, cucumber and okra and other cereals like maize in the dry season when the watertable is low.

Materials and Methods

Groundwater Recharge

The watertable Fluctuation method (Meinzer, 1923; Hall and Risser, 1993; Ramussen and Andreasen; 1959; Healy and Cook, 2002; Risser *et al*, 2005) was used for estimating recharge. This method was based on the premise that the rise in groundwater levels in unconfined aquifers was due to recharging water arriving at the watertable. Recharge was calculated using the formula:

$R = Sy\frac{\mathrm{dh}}{\mathrm{dt}} = Sy\frac{\Delta h}{\Delta t}$ Where, R= Recharge (mm/month), Sy= Specific yield, dh or Δh = Change in watertable height (mm), dt or Δt = Time interval (month).

Wetland groundwater level fluctuations was monitored through a network of 14 piezometers installed using a hand auger along a longitudinal and transverse transect at the Besease site as shown in Figure 1. The piezometers consisted of PVC pipes of 7.62 cm diameter screened over the bottom 20 cm with holes of 0.3 cm diameter. The depth of the pipes ranged from 1.8- 3 m. Sand was packed around the screens and the rest of the annulus hole was backfilled with auger cuttings and then grout placed on the top to prevent surface water entry. The cup covering the top of the pipes were not hermetically closed to prevent build up of pressure in the piezometer during phases of groundwater rise. Depth to watertable was measured for every two days with greater frequency during rain events by inserting a measuring tape down into the piezometers and observing when it encountered the water surface. The elevations of the piezometers were surveyed to benchmarks to allow adjusting the water levels in the wells to the local datum.

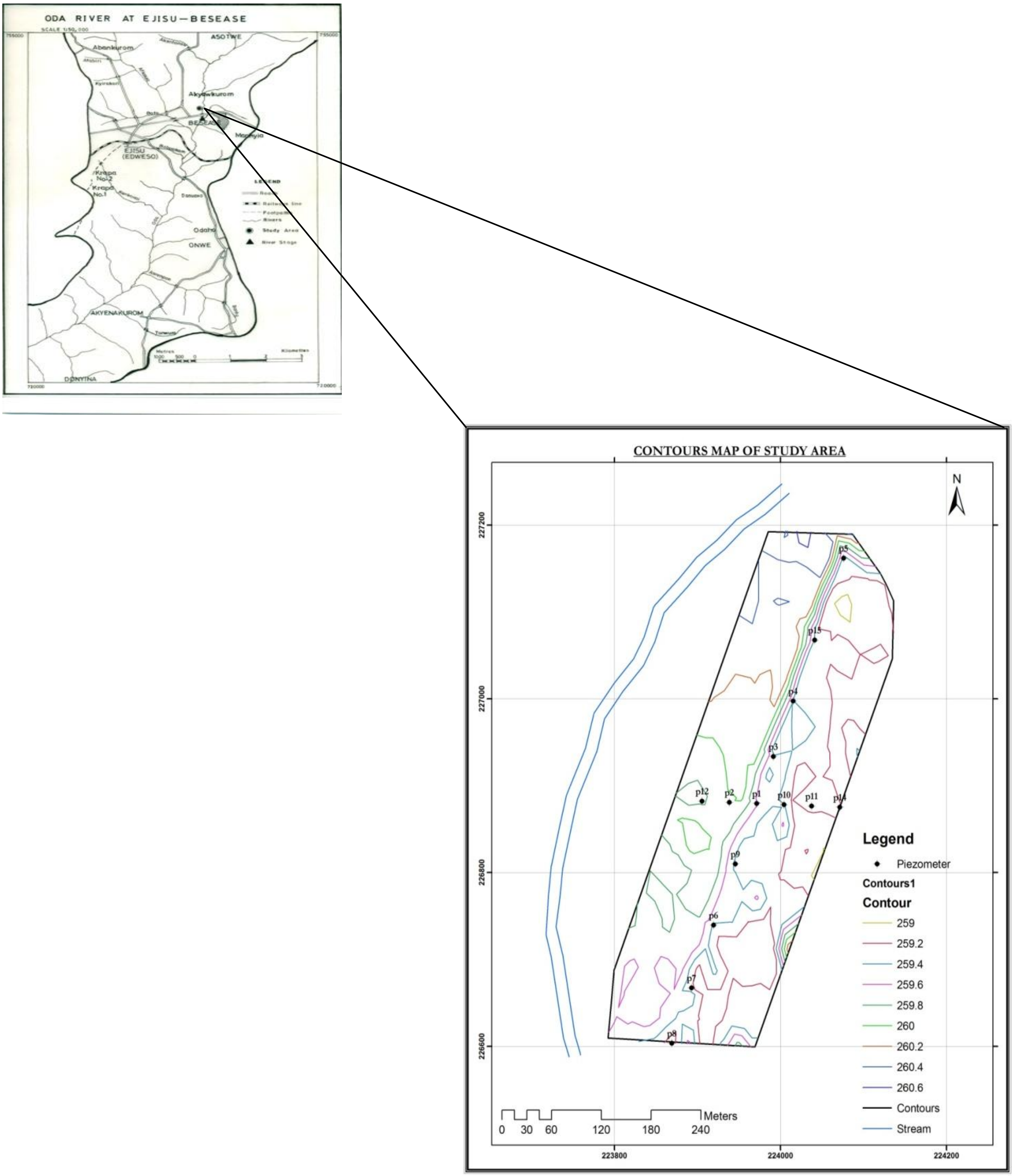

Figure 1 Map of the Besease catchment site showing field piezometric networks

Groundwater Flow Model

The purpose of building a conceptual model is to simplify the field problem and to organise the associated geological and hydrogeological data so that the system can be analysed more readily. For groundwater model calibration, the manual trial-and-error technique for adjustment of parameters was applied. The most important criteria that were used to check the calibrated model are the Root Mean Square Error (RMSE), the Mean Absolute Error (MAE), Mean Error (ME) and mass balance. The time dependent field data such as recharge, head observations and river stages were prepared in ASCII format files for the model input modules.

Model Development

The simulated flow was developed from a three dimensional groundwater flow model through a varied number of steps; including the conceptual model, analytical solution, numerical code selections and field data inputs. The study area was structured and constructed, based on the simplification of a conceptual model, to represent the physical properties of the groundwater system. The selected code for the numerical model was PMWIN processing MODFLOW version 5.3 (Chiang and Kinzelbach, 2001) as code environments for data input and output management. Descritisation of the model domain plays an important role in the cause of the modelling. The model region was made up of two layers and was divided into grids, the layers had 65 columns and 38 rows using the 10×10 m grid cell spacing resulting in 247000 grid cells and this was used to represent the entire model area of 72 ha. Cells in the no flow boundary region were defined as inactive using the I BOUND array in MODFLOW. The total number of active grid cells in the model was 90400 cells.

Model Parameters and Stresses

The surface topography was derived from a survey carried out over the area and the aquifer extent was also structured based on the available details of the boreholes stratigraphic unit. The mean thickness of the top unconfined layer was 2.3 m comprising sandy loam of the study site. The second layer below had a thickness of 1.2 m and characteristic silty sands, specified on the basis of a geological formation which enhances transmission of water. Fourteen observation piezometers, where the water level measurements were averaged every month, were used for model simulation in the model area. Model simulations were completed over a monthly time period. In MODFLOW, recharge is normally estimated and entered as input values into the recharge package. The boundary condition in the MODFLOW groundwater model is effectively represented by specifying net bottom flux of watertable fluctuation as a recharge flux. For the two year period (730 days) a recharge of 757 mm as input into the model and was applied uniformly over the model domain. Initial values of hydraulic conductivity in the Besease valley aquifer was evaluated from falling head test and mini disc infiltrometer test. The values were used as initial parameter values for the model. Two hydraulic conductivity layers were specified. For the top layer, due to spatial heterogeneity of vertical hydraulic conductivity, a range of 0.02-0.039 m/d was specified. A range of 0.2-0.39 m/d was specified as the horizontal conductivity of the top layer. For the bottom layer, an arbitrary value of 0.07 m/d was specified for both vertical and horizontal hydraulic conductivities. For the river package, riverbed conductance values of between 2.0 x 10^2 m/d and 2.30 x 10^2 m/d were assigned to the package and a minimum elevation of 257.5 m was approximated and used to adjust the available DEM data.

Results and Discussion

Model Calibration

The model was calibrated using both steady and transient mode. The steady state flow simulation was performed to first calibrate model parameters. This was done to obtain a tolerable distribution of the initial hydraulic head relative to measured data. The vertical and horizontal hydraulic conductivity values of the two layers were adjusted to get good fit for conductivities of the layers. In addition, effective porosity, specific storage, storage coefficient and specific yield of the sub-surface were adjusted to fit the level of fluctuation occurring within the floodplain wetland. The adjustment of the conductivities and other parameters shifted the percent of discrepancy for each time step to be less than one (1%) which meant that the model equation had been solved correctly (Harbaugh, 2005).

Table 1: Adjusted parameters for the groundwater flow model

Properties	layer 1	layer 2
Horizontal Hydraulic conductivity	0.12 - 0.59	0.4
Vertical Hydraulic conductivity	0.015-0.059	0.07
Effective porosity	0.20-0.24	25
Specific yield	0.06 m^3/d	0.015 m^3/d
Specific storage	0.05	0.001
Storage coefficient	0.01	0.001

The steady state simulation became possible by assuming the starting hydraulic head from the interpolated hydraulic head of the boreholes and the river in January 2009. For transient calculations of groundwater flow simulation, an initial condition created from the steady state was used. The period September to October 2010 was chosen for the calibration, as detailed hydraulic head measurements were available for this period. The aquifer received 753.83 mm as aerial recharge from the watertable fluctuation method. The time step for the two year simulation was divided into 24 stress periods and each stress period represented a month. A time step of 4 days was chosen so that the total time step equalled one month while the total simulation time equals 370 days. The output from the model simulation shows monthly flow maps which depends on the variations of the recharge and the river package. The calculated head values for the last step of each stress period were noticed to show slight differences in head contours. Figures 1 and 2 show plots of observed and calculated heads for the piezometers 1 and 14, for which the calculated head follows the pattern of the observed head. Water levels in the piezometers are always elevated in the rainy season and lowered in the dry season; the piezometers in the Besease inland valley were used to represent sections of the wetlands. The rises in the hydraulic heads of the simulated hydrograph are similar and follow a pattern, while the observed hydraulic head shows some differences. The variability in the observed heads is likely to be a result of heterogeneity in the sub-surface aquifer structure. The model calibration criteria were adjusted with the result of the average root mean square error (RMSE) of 0.099 m and

0.134 m, absolute mean error (MAE) of 0.067 m and 0.084 m and mean error (ME) of 0.016 m and -0.006 m for P 1 and P 14 respectively. The watertable bottom flux used as a recharge estimate resulted in a fit between the simulated hydraulic head and observed sub-surface water level fluctuation. The level of compatibility observed from the calibration criteria of P1 and P 14 gives an indication that the model calibration needs to be improved. A more accurate calibration will not be justified when given a lack of spatial data, for instance the local flow pattern, hydraulic properties with depth. Also dynamics in phreatic watertable fluctuations, topography and other parameters would be required in more detail to develop a validated model of the accuracy required for the management of the inland valley in the Ejisu-Besease Oda River basin.

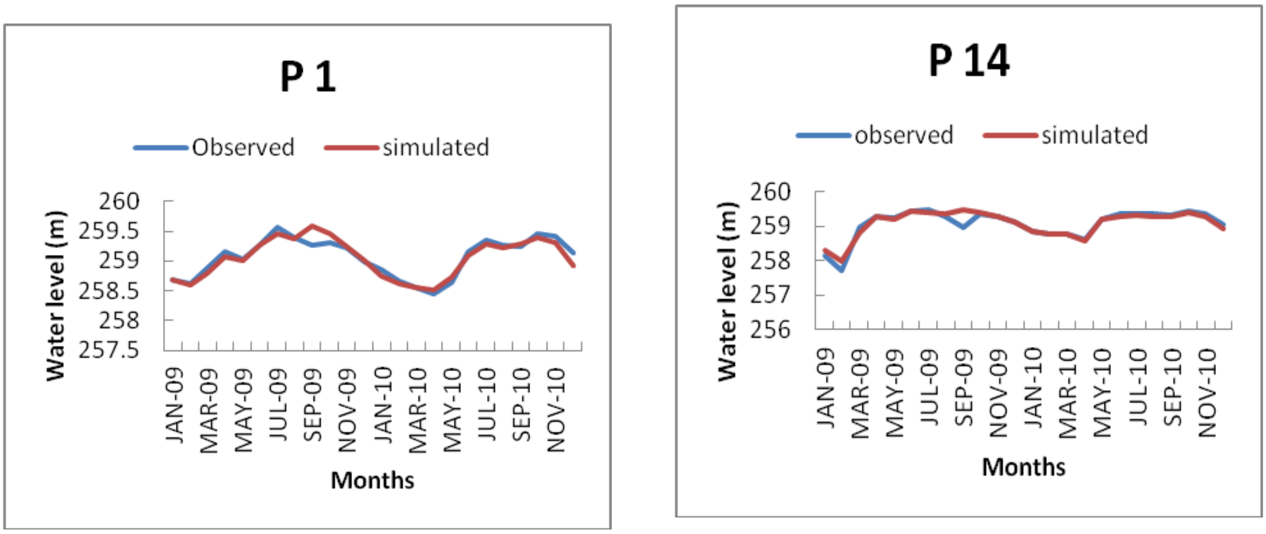

Figure 2: Observed versus Simulated head at the end of each stress period for piezometer 1 and 14

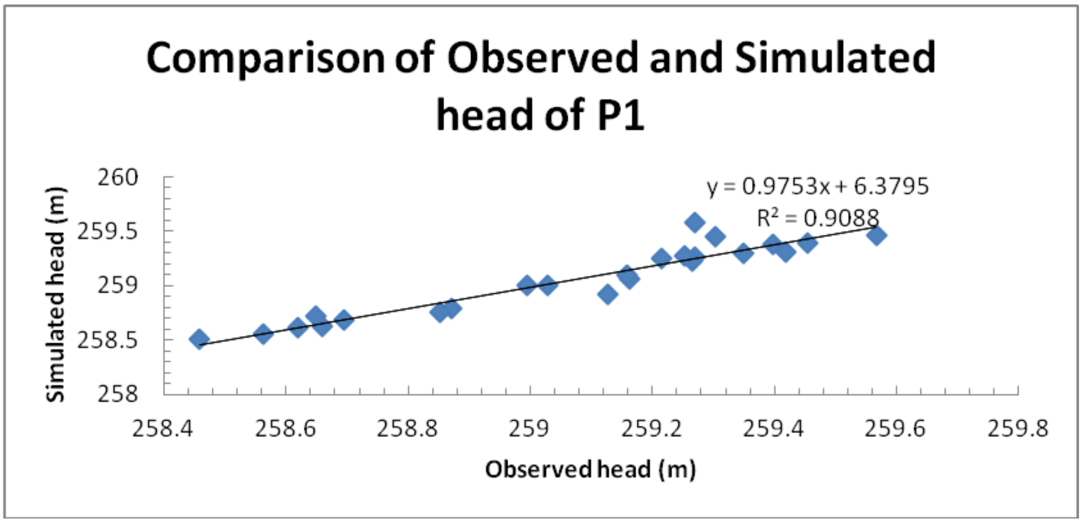

Figure 3: Comparison of simulated and observed heads in the Besease Inland valley wetland for a period of two years (January 2009 to December 2010)

The simulation of the sub-surface hydraulic head indicates a systematic variation relative to the Oda River in response to changes in the rainfall pattern in the moist semi-decidious climatic region. Over the months of September 2009 and March 2010 (Figures 3 and 4) distinctive patterns of hydraulic heads were observed. As depicted in the month of January 2009 where the simulated hydraulic head showed a lowered watertable of 258.5-258.67 m with a difference of 0.17 m. Also in the period of February to March 2010 the hydraulic head experienced in the valley varied between 258.51m and 258.64 m below the topographic surface with the lowest in March (Figure 4). The lowering of the watertable in the dry periods even with total rainfall input of 34.9 mm in January 2010 and 49.6 mm in February 2010 replenished the soil moisture deficit but could not reach the watertable to recharge it (Figure 4 and Table 2). These recorded rainfall input in January and February 2010 which could not raise the watertable suggest that antecedent moisture in the vadoze zone should be taken into consideration in recharge characteristics of unconfined aquifers in response to rainfall events. This also shows that moisture levels in the unsaturated zone holds part of the seasonal replenishment in these unconfined aquifers. In the wet season the precipitation recharge the groundwater by raising the watertable at an average rate of 0.5 m/month. The wetland became saturated in the months of June and July for both 2009 and 2010 water years. The piezometric watertable rose above the ground surface for all the piezometers except that of P1 and P2 but all the pipes experienced a watertable rise above the ground surface in the month of July. This was evident by the fact that the soil got saturated in most parts of June and July. However, the model under-predicted the simulated hydraulic head in June 2009 with an estimated head of 259.36 m but over-predicted the hydraulic heads in September 2009 experiencing a simulated head of 259.57 m and that could be attributed to the accumulated high river stage level in September 2009 which showed some interaction between the Oda River and the inland valley. A bi-direction of sub-surface water flow between the Oda River channel and the wetland hydrologic system is inferred as having a temporal and spatial variation.

Mass Balance

The calibrated groundwater model produced an estimated groundwater budget for the model domain. The water budget accounts for the sources of water for recharge or discharge of a hydrologic system on monthly basis. The inputs into the model were derived from aerial recharge, river leakage into the wetland and storage out of the wetland. The calculated water budget components include storage, recharge, river leakage in, and river leakage out which were evaluated. The volume of water in m^3 and its percentage was calculated for each component of the hydrologic budget. The cumulative mass balance at the end of the run period of 24 months (730 days) for the transient model demonstrates the importance of recharge as a water balance input. The model underestimated the recharge of 24.30 mm in June 2009 and this lends credence to the fact that the entire wetland experienced saturation in the middle of the month where the watertable was near or above the ground surface. The storage terms described by MODFLOW in Table 2 represent the quantities of water that are either released from storage as the watertable falls and water drains from open pores in the wetland substrate or water that is taken up into storage as the watertable rises and the wetlands become increasingly saturated (Bradley, 2002).

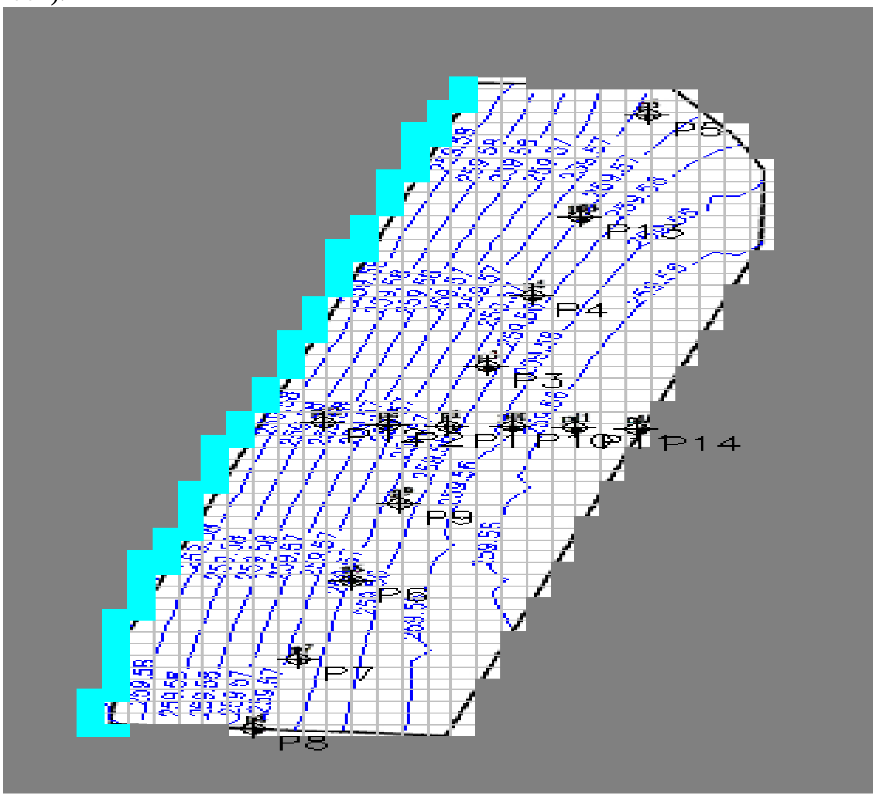

Figure 4: Depth of estimated hydraulic head of Inland Valley in September 2009

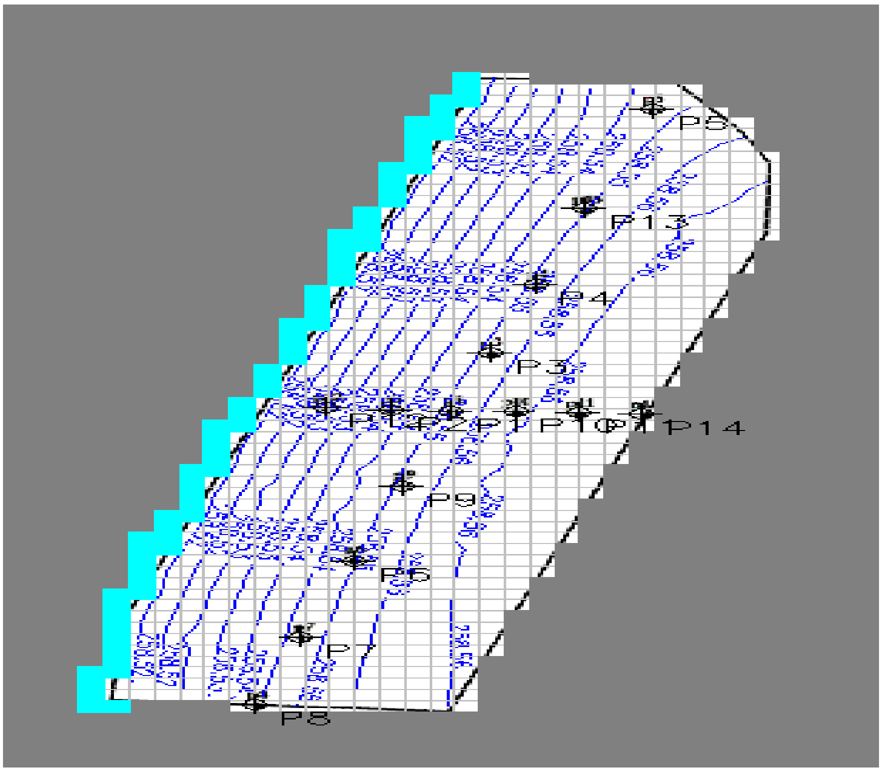

Figure 5: Depth of estimated hydraulic head of Inland Valley in March 2010

For instance in the month of June 2010 a total amount of 9668.405 m³ moved into storage to saturate the wetland and it was in one of these periods when static water level in all the piezometers rose above the ground surface during field observations but this was under-predicted by the model (Figure 2). The extent, depth, frequency, timing and duration of water ponding at the surface of the wetlands are important parameters controlling the extent of soil moisture for the sustenance of the river (Nyarko, 2007). Nyarko (2007) observed that water ponding in the Pwalugu wetland to a depth of 0.65 m as measured during fieldwork in August 2005 was the result of a complex and variable combination of groundwater upwelling and accumulation of rainfall on the saturated surface. The impact of the dry period lowered the watertable indicating a decrease in aquifer storage. The dry stress periods with low or no recharge experienced a low storage input, coupled with high active plant evapotranspiration could not raise the watertable (Figure 4). Ransom and Smeck (1986) concluded that the depth to watertable was a function of both precipitation and evapotranspiration for seasonally wet soils in southwestern Ohio. Short and long-term precipitation patterns need to be considered for projects that require an assessment of developing wetlands for crop production. Total annual or even seasonal precipitation may not determine the overall watertable fluctuations of a wetland. However, intense but infrequent precipitation events may result in a short-term, elevation in the watertable, but only sustained precipitation during the summer months will maintain elevated watertables (Winter and Rosenberry, 1995). Data on the crop water requirement of dry season cultivated crops and vegetables can be applied to irrigate the field to elevate the watertable to an appreciable level otherwise excess water applied or high rainfall variability occurring in the area can cause the watertable to rise above the root zones of the plant due to the high storage capacity of the field depicted from the model (Table 2). The values for storage are substantial indicating the temporal variability in the watertable with continuous movement of water to and from storage over an annual cycle (Bradley, 2002). Also the accumulated recharge causes an increase in storage of the subsurface groundwater which can be pumped out from the wetland substrate to sustain dry season cultivation. The monthly recharge generated suggests a significant contribution of water from wetlands into the river. Also there is a form of interaction between the inland valley wetland and the Oda River and this condition vary from period to period depending on the river stage. Over the two year period influent recharge (i.e. seepage into the wetlands) was extremely small. In the month of August 54.42 mm of water leaked into the wetland from the river as against 53.95 mm seeping into the river from the wetland. Seepage from the wetland to the river shows one of the main losses in the volumetric water budget of the valley. However, the difference between leakage into and out of the wetland were much reduced as water levels in both the river and the wetland were much higher and this was evident in the month of September 2009. The interaction between the inland valley and the river is bidirectional with most of the flow coming out from the wetland which affirms the fact that floodplain wetland serves as a moisture buffer and supplies the river with water during low flow conditions. A total of 297.91 mm leaked out of the wetland system from November to December, 2010 to contribute to the sustenance of the Oda River. In this situation, floodplain wetland contributes as base flow to the Oda River in the dry season.

Table 2 Cumulative water budget for different components in the model area

Time	Flow Term	Inflow (m^3)	%	Outflow (m^3)	%
1st Year	Storage	52760.98	42.84	49538.39	40.23
	River Leakage	39089.26	31.74	73589.83	59.77
	Recharge	31295.92	25.42	0	0
	Total	123146.15	100	123128.22	100
2nd Year	Storage	50020.39	40.6	48257.54	39.17
	River Leakage	41819.72	33.95	74954.78	60.83
	Recharge	31355.43	25.45	0	0
	Total	123195.55	100	123212.32	100
1st & 2nd Year	Total	246341.7	100	246340.50	100

Sensitivity Analysis

The specific objective of a sensitivity analysis is to understand the influence of various model parameters and hydrological stresses on the aquifer system and to identify the most sensible parameter(s), which will need a special attention in future. In the analysis, the magnitude of change in estimated heads from the calibrated solutions was used as a measure of the sensitivity of the model to that specific parameter. To determine the calibrated solution's sensitivity to the aquifer properties hydraulic conductivity and specific yield were varied in turn by multiplier factors of 0.4, 0.6, 0.8, 1.2 and 1.4 for the two layers. Specific storage was varied by an order of magnitude each way from the calibrated value in order to see a significant alteration. Only one parameter was varied at a time in order to quantify the effect of the changes of the solution and any effect were evaluated by the same statistical methods used to evaluate the model calibration such as the RMSE. The model is highly sensitive to increase in hydraulic conductivity and insensitive to decrease in hydraulic conductivity which produced a lower RMS error. Also for specific yield the multipliers of 1.2 and 1.3 produced a RMS error greater than the calibrated value while for other variables specific yield decreases as RMS error decreases which shows that the model is insensitive to decrease in specific yield. For specific storage the variables 0.0005 and 0.00001 for layers 1 and 2 respectively plots slightly below the value of 0.005 and 0.0001 for the calibrated model while the other variables 0.05 and 0.001 for layers 1 and 2 produced a much higher RMS error. The sensitivity of the calibrated model to variations in hydraulic conductivity and specific yield which were increased and decreased by a multiplying factor show that these aquifer variables were within realistic bounds for sand, loam and silty-sands . The specific yield and specific storage which exhibited lower RMS errors than their calibrated values indicated that the aquifer material has a specific yield values of 0.024 and 0.006 and specific storage values 0.0005 and 0.00001 for layers 1 and 2 than the calibrated values. The lower specific yield values which produced a RMSE lower than the calibrated values of 0.06 and 0.015 for the two layers may suggest that the aquifer material is less sandy.

Groundwater Flow Prediction

A groundwater flow model may be used to predict future flow conditions, such simulation estimates the hydraulic response of an aquifer, and also it can forecast the pumping rate required to monitor the hydraulic heads. Pumping strategy is a set of spatially and possibly temporary distributed rate of extracting water from aquifer (Parelta, 2004). Hydraulic heads for 2012 were predicted, in the transient simulation there were two stress periods, and one for dry period of 240 days when pumping is occurring and no recharge and the other for the wet period of 120 days when there is recharge only. Four (4) wells were distributed to the model domain. Water is extracted from the wells at a discharge of 100 m^3/d. The predictive scenario show a decline in the watertable and consequently P8 became dry which suggested that the area where the piezometer P8 is located at the southern part of the field will encounter a seasonal decline of groundwater table due to influence of local-scale conditions.

Conclusions and Recommendations

An initial conceptual hydrogeological model of the Oda River basin in Besease with unconfined, semi confined, two layered aquifer was developed with differing hydraulic characteristics. The calibrated MODFLOW model was more acceptable with the average root mean square error (RMSE) of 0.099 m and 0.134 m, (MAE) of 0.067 m and 0.084 m and average (ME) of 0.016 m and -0.006 m for P 1 and P 14 respectively. The Water Table Fluctuation method used as an estimate of groundwater recharge gave a better fit between the simulated hydraulic head and observed sub-surface water level fluctuation. For this inland valley bottom the relationship between the valley bottom and the Oda River showed that the river level represents a base level to which the valley bottom watertable adjusts. From the water budget produced by the model it was noticed that in the month of June 2010 a total amount of 9668.405 m³ of water moved into storage to saturate the wetland. It was found out from the results that a decline in simulated hydraulic height which showed a decrease in storage in the monthly dry stress periods is a critical predictive criterion because it defines the effective rooting depth (ignoring the extent of the capillary fringe), the soil water storage depth and drainage requirements, re-establishes the dry season agricultural unsaturated zone and a distinguishing characteristic for classifying the inland valley bottoms into soil and water management regimes. Also the simulated groundwater heights which showed a fluctuation of one (1) m at the end of the simulated stress periods indicates that an appropriate irrigation method could be adopted to raise the watertable to saturation to ensure a year round rice production or the watertable could be raised to an optimum height to sustain vegetable production in the dry season.

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