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Groundwater resources assessment using numerical model: A case study in low-lying coastal area

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ABSTRACT: The impacts of climate change and human pressure in groundwater have been greatest threats facing small islands. This paper represents a case study of groundwater responses towards the climate change and human pressures in Manukan Island Malaysia. SEAWAT-2000 was used for the simulations of groundwater response in study area. Simulations of six scenarios representing climate change and human pressures showed changes in hydraulic heads and chloride concentrations. Reduction in pumping rate and an increase in recharge rate can alter the bad effects of overdrafts in Manukan Island. In general, reduction in pumping rate and an increase in recharge rate are capable to restore and protect the groundwater resources in Manukan Island. Thus, for groundwater management options in Manukan Island, scenario 2 is capable to lessen the seawater intrusion into the aquifer and sustain water resources on a long-term basis. The selection of scenario 6 is the preeminent option during wet season. The output of this study provides a foundation which can be used in other small islands of similar hydrogeological condition for the purpose of groundwater resources protection.

Keywords: *Climate change; Human pressure; Pumping rate; Recharge rate*

INTRODUCTION

Freshwater in tropical small islands usually depends on recharge, quantity and surface storage (Aris *et al*. 2008). Most of tropical small islands have limited sources of freshwater, no surface water or streams in exploitable form. Thus, fresh groundwater is the sole option to meet the water demand in tropical small islands. The inhabitants of these islands mostly depend on groundwater to meet their needs, particularly for drinking and tourism purposes. The freshwater lens on tropical small islands may easily be overexploited or polluted due to dense development impacted by tourism expansion combined with improper management and vulnerable to climate change (Beller *et al*., 1990; Griggs and Peterson, 1993; Singh and Gupta, 1999; Rejani *et al*., 2008).

Climate change impacts such as recharge rate and human pressure such as pumping rate on freshwater lens control the shape and thickness of the freshwater lens. Recharge rate and pumping rate on freshwater lens have direct impacts on water resources and its management. Moreover, environmental management protection of coastal area must be established by the regulations as well as supervision on enforcement of laws (White *et al*., 2007; Nouri *et al.,* 2008a). Climate variability causes changes in rainfall patterns and groundwater recharge in coastal environment such as small islands. Effects of climate change will alter the global hydrological cycle in terms of distribution and availability of regional water resources. A warmer climate with its increased climate variability will increase the risk of floods and droughts (IPCC, 1997). Many studies highlighted in literature on the decrease in recharge which gives problems to groundwater resources (Zhou *et al*., 2003; Moustadraf *et al*., 2008; Puraji and Soni, 2008). Comparatively, according to Vaccaro (1992), little research has focused to determine the sensitivity of the aquifers to the changes in critical inputs such as an increase in precipitation and recharge. Recharge rates cannot be ignored despite to the fact that sustainable pumping rates can be estimated without them. IPCC (1997) indicated that in warmer climate there is a risk of flood impacts by climate changes. Studies done by Devlin and Sophocleous (2005) and Sophocleous and Devlin (2004) showed that sustainability is a function of

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recharge. Human pressure deals with overdrafts of freshwater by pumping well distort the natural recharge-discharge equilibrium. Unregulated exploitation of groundwater due to overpumping would cause irreversible deteriorations of groundwater quality due to drawdown of water table or upconing of the saltwater interface. Overdrafts of fresh water by pumping well distort the natural recharge-discharge equilibrium causes drawdown of the watertable a rise or upconing of the saltwater interface (Aris *et al*., 2008). Thus, it is vital to maximize the economic benefits of tourism (Nouri *et al.,* 2008b)

Groundwater modeling has emerged as a powerful tool to help managers to optimize and predict the groundwater resources. Groundwater models apply the advantages of recent advances in computer technology, provide real time modeling, visualization and analysis of two and three dimensional flow and transport softwares (Abdul Rahim and Abdul Ghani 2002; Welsh 2008). User friendly graphical interfaces make it easier for models to be used (Konikow, 1996). Numerical groundwater models such as SEAWAT-2000 have dominated the study of complex groundwater problems because of their ability to tie data and physical principles together into a useful picture of the studied area, capable to produce greater and accurate. Simulation of groundwater modeling is an excellent tool to understand the behavior of an aquifer system subjected to natural and artificial stresses such as pumping (Rejani *et al*., 2008). Examples of SEAWAT-200 applications in groundwater flow and solute transport studies were presented in Rejani *et al*. (2008) in Balasore, India, Werner and Gallagher (2006) in Pionner Valley, Australia as well as Don *et al*. (2005) in Kyushu Island and Ariake Sea, Japan.

Considering the sensitivity of aquifers to climate change (recharge rate) and human pressure (pumping rate) in Manukan Island's current condition, present study using a three-dimensional finite-difference numerical model is concerned to develop an understanding of groundwater sustainability under current aquifer conditions. Secondary objectives include evaluating the groundwater resource affected by vulnerable to climate change (recharge rate) and human pressure (pumping rates) using variable density SEAWAT-2000 code (Guo and Langevin, 2002), a combined version of MODFLOW and MT3D. This output is to gain insights about the future changes in groundwater due to vulnerable to climate change (recharge rate) and pressure of island resources (pumping rates) in hydraulic levels and chloride concentrations. Lastly, the output will be able to recommend the suitable groundwater management option in study area. The output of this study is foundation for more rebust evaluation of the groundwater system in any tropical small islands. It is important to study the deterioration of groundwater withdrawal and work out a comprehensive scheme of groundwater exploitation consistent with the constraints existing on the island.

Low-lying area of Manukan Island from the hilly area to shoreline was selected for this where all the wells for groundwater extraction are located on the low lying area of the island (8 wells have been shut down and only 1 well is currently operating). Samplings were done monthly from October 2008-March 2009 which hydraulic heads and chloride concentrations data were collected from the well and boreholes. According to Anderson and Woessner (1992), in transient simulation six-ten months data are adequate to simulate and analyze case studies (as in this study) as such done by He *et al.* (2008). On the other hand, one year data set is suitable for prediction using numerical groundwater model such as done by Lin *et al.* (2008) in numerical simulation in Alabama Gulf Coast, USA.

MATERIALS AND METHODS

Site description

Manukan Island (5º 57'-5º 58'N and 115º 59'-116º 01'E) in Fig. 1 covers an area of 206,000 m^2, about one and half km long and three km wide in the middle. The area has a warm and humid climate and receives annual rainfall between 2,000 and 2,500 mm. Almost 80 % of the area is covered by dense vegetation on high relief area (eastern part), while the rest of the area is located on the low lying area of the island (western coastline).The island consists of unconfined sandy aquifer, underlain sedimentary rock (sandstone and shale). The sedimentary rock dips towards the low lying area (east-northeast) with dipping angles of 15º–45º. The sedimentary rock forms a slight symmetrical syncline in the low area and can be observed in several locations around the island (Basir *et al*., 1991; Abdullah *et al*., 1997; Tunku Abdul Rahman Park, 2007). Abdullah *et al*. (2002) conducted a study on the morphological of the island found that the thickness of the aquifer from the ground surface to bedrock are approximately,

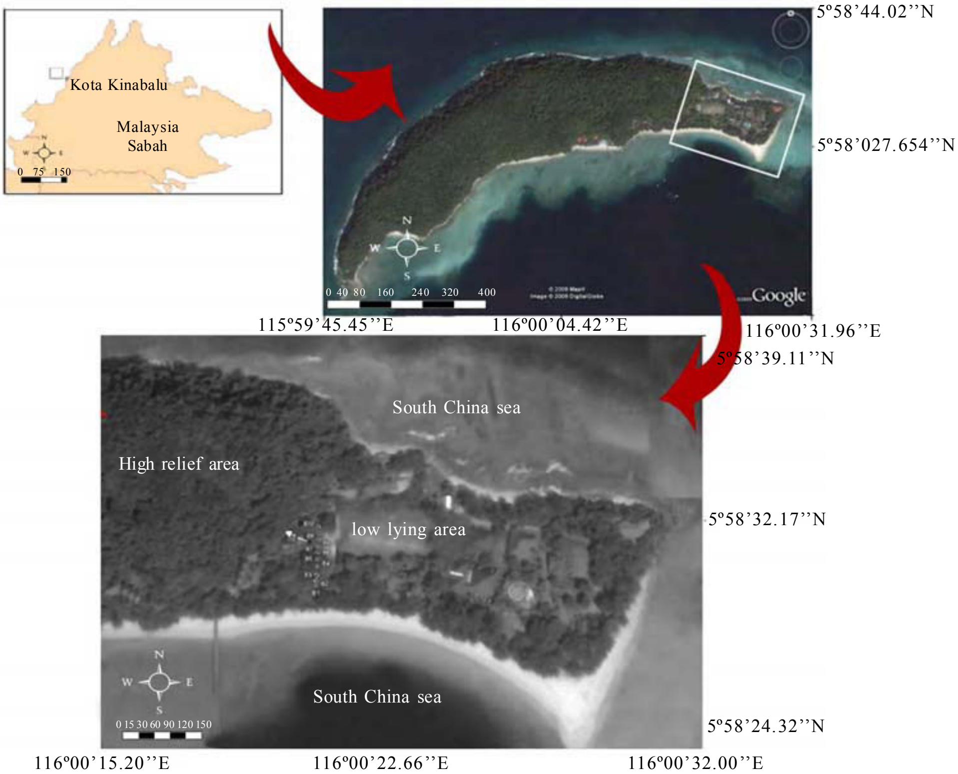


Fig. 1: Location of the study area (a) Manukan Island (b) high and low-lying

5.7 m (northern part), 11 m (southern part) and 12 m (at the middle). Generally, the profiles at low lying area are flatter and thinner than hilly area. On the low lying area of Manukan Island, the small area and low elevations lead to very limited water storage (Abdullah *et al*., 2002). The flat low lying area of the island has been developed for tourism activities. There are also accommodation available with excellent facilities (i.e., 20 unit chalets, a clubhouse, restaurant, souvenirs, diving centers and recreational facilities such as a swimming pool, football field, squash and tennis courts) and good infrastructure support (i.e. water, electricity, desalination plant, sewerage system and even a solar powered public telephone) (Abdullah *et al*., 2002; Aris *et al*., 2007; Aris *et al*., 2009).

Manukan Island only has fresh groundwater option as a water supply. Tourism impacts on small islands such as Manukan Island have made more severe to their limited water resources (Wong, 1998). Number of tourists arrivals to this island about 400 % from 1997 to 2004 which attracted by famous dive sites in Manukan Island (Aris *et al*., 2008). This resulted in remarkable increase of groundwater extraction to meet the groundwater supply and domestic needs. Eight dug wells in low lying area which have been used for groundwater extraction have been shut down due to incursion of seawater into the island's aquifer. Only one dug well is currently operating as a pumping well in groundwater extraction to meet the domestic supply. With this current situation, large pumping of groundwater will lead to the depletion of groundwater and deterioration in its quality. In general, small islands are highly susceptible to seawater intrusion due to its highly permeable aquifer. Manukan Island revealed that the mixing rates of seawater intrusion in low lying area of Manukan Island were about 13 %. The seawater intrusion into Manukan Island's aquifer is marked by the presence of Na-Cl water type. Seawater intrusion becomes a threat when the interface moves far enough inland to render drinking water wells salty and unusable. Intensive exploitation of groundwater and wells shutdown in Manukan Island's aquifer is indicating that the natural equilibrium between fresh and seawater has been disturbed (Aris *et al*., 2007; 2008).

Model design

Low lying area from the hilly area to shoreline was selected for this study (Fig. 1) as it has been developed for tourism activities. Moreover, all the wells for groundwater extraction are located on the low lying area of the island (8 wells have been shut down and only 1 well is currently operating). A pumping well and 10 boreholes (installed by hand auger manually) were distributed across the study area (Fig. 1) to provide a good horizontal and vertical spatial distribution of hydrologic data. The operation of the well and the boreholes will be able to show the changes in hydraulic levels and chloride concentrations resulting from pumping from shoreline. Hydraulic heads and chloride concentrations data were collected from October 2008-March 2009 from the well and boreholes. Water samples were pumped through silicon tubing to polyethylene sampling bottles via a peristaltic pump. Analysis for chloride was done using argentometric method (APHA, 1995). SEAWAT-2000 is the latest modeling software available in groundwater modeling that couples flow and transport together (Guo and Langevin, 2002). SEAWAT-2000 couples the flow and transport equations of two widely accepted codes MODFLOW (Mcdonald and Harbaugh, 1988; Harbaugh *et al*., 2000) and MT3DS (Zheng and Wang, 1999) with some modifications to include density effects based on the extended Boussinesq assumptions.

It reads and writes standard MODFLOW and MT3DS input and output files so that most existing pre- and post processors for those packages can be used. The governing flow and transport equations in SEAWAT-2000 are as in Eqs. 1 and 2. The SEAWAT-2000 package is very flexible and user friendly. This package has been very useful to simulate variable density flow through complex geological. One advantage of SEAWAT is that it uses MT3DMS to represent solute-transport, the program contains several methods for solving the transport equation including the method of characterization, a third-order total-variation-diminishing (TVD) scheme and an implicit finite-difference method. Hence, SEAWAT-2000 software package was selected in the present study to simulate the groundwater flow and solute transport to predict the behavior of groundwater of Manukan Island aquifer. The groundwater flow is as follow:

$$\frac{\partial}{\partial \chi_i}\left[\rho K_f\left(\frac{\partial h_f}{\partial \chi_i}+\frac{\rho-\rho_f}{\rho_f}\frac{\partial_z}{\partial \chi_i}\right)\right]=\rho S_f\frac{\partial h_f}{\partial_t}+\theta\frac{\partial h_f}{\partial_t}+\partial\frac{\partial_p}{\partial_t}-\rho s q_s \quad (1)$$

Where;

X_i = i^{th} orthogonal coordinate

K_f = equivalent freshwater hydraulic conductivity (L/T)

S_f = equivalent freshwater specific storage (1/L)

= equivalent freshwater head

t = time (T)

θ = effective porosity (dimensionless)

= density of source and sink (M/L_3)

q_s = volumetric flow rate of sources and sinks per unit volume of aquifer (1/T)

The transport equation is as followed:

$$\frac{\theta\left(\theta C^k\right)}{\theta_t}=\frac{\partial}{\partial_x}\left(\theta D_{ij}\frac{\partial C^k}{\partial x_j}\right)-\frac{\partial}{\partial x_i}\left(\theta v i c^k\right)+q_s C_s^k+\sum R_n \quad (2)$$

Where,

C^k = dissolved concentration of species, k (M/L^3)

= hydrodynamics dispersion tensor (L^2/T)

C_s^k = concentration of the source or sink flux for species, k (M/L^3)

= the chemical reaction term (ML^3/T)

To evaluate the effects of pumping and recharge rates, a three dimensional model using SEAWAT-2000 has been developed. The conceptual model for this

Table 1: Input parameters for the model and simulation strategies for this study

Parameter	Value
Hydraulic conductivity (K_x, K_y & K_z)	
Layer 1	5.42E-4, 1E-5, 1E-5
Layer 2 (Sedimentary rock)	3.4E-7, 1E-5, 1E-5
Total porosity	0.30
Effective porosity	0.15
Specific storage	0.0014
Specific yield	0.35
Longitudinal dispersivity	1 m
Horizontal transverse dispersivity	0.1 m
Vertical transverse dispersivity	0.01 m
Constant head	0 m
Recharge concentration	0 mg/L
Constant head concentration	19999 mg/L
Initial concentration	Based on October 2008
Initial head	Based on October 2008

study was developed based on the surface elevation contour map, information collected during boreholes construction and data from Abdullah (2001). The model grid (Fig. 2) consists of 34 columns and 79 rows with grid spacing of 1093 (x-direction) and 906 m (y-direction). The unconfined layers divided into 2 layers based on the hydrogeological information. In the present study, it is assumed that the hydraulic conductivities of two layers vary along horizontal and vertical directions. The soil samples were taken into lab for soil physical parameters (hydraulic conductivity and porosity). Representative properties of the Manukan Island aquifer (Table 1) were assigned to active model cells. Constant head cells were assigned along the bottom of the ocean. A chloride concentration of 19,999 mg/L was assigned for constant concentration while 0 mg/L for recharge concentration. Initial condition (initial concentration and heads) for model at active model cells (layer 1) was based on October 2008 data. Based on groundwater data availability, one day was chosen as the time step in this study and to be increased by a multiplier factor by 1.2 within which all the hydrological stresses can be assumed constant. Time step is required for transient state. Generally, the smaller the time step, the more accurate the predicted results, although it will require excessive computation time. Too large time steps will result in instability output (Spitz and Moreno, 1996). Temporally, the simulation numerical model is transient with a total simulation time of six months from October 2008-March 2009. A total of 6 months (October 2008-March 2009) was used in the model, with each stress period representing 1 month of simulation month. In this study, model calibration is achieved through trial and error approach by adjusting the zonation, valuesof hydraulic conductivities, dispersivity and effective porosity until the calculated values match the observed values to a

Table 2: Simulation modeling for different scenarios representing vulnerable to climate change (recharge rate) and pressure of island resources (pumping rates)

Simulation 1 : *Human Pressures (Pumping Rate)*	Description
Scenario A	Assuming of constant recharge rate of 600 mm/yr The second pumping scheme (A) is to be at the current rate in the study area which is 0.072 m^3/day
Scenario B	The first pumpage scheme (B) was assumed to be 25% less than the current rate
Scenario C	The third pumping scheme (C) is to increase the current pumping rate by 25% in order to meet the current tourist and water demand
Simulation 2: *Climate change (Recharge Rate)*	
Scenario D	Manukan Island aquifer at current pumping rate (0.072 m^3/day) and recharge rates (600 mm/yr)
Scenario E	Manukan Island aquifer at current pumping rate with an increased in recharge rate by 25%
Scenario F	Manukan Island aquifer at reduced pumping rate influence by pressure of island resources with an increased in recharge rate by 25%

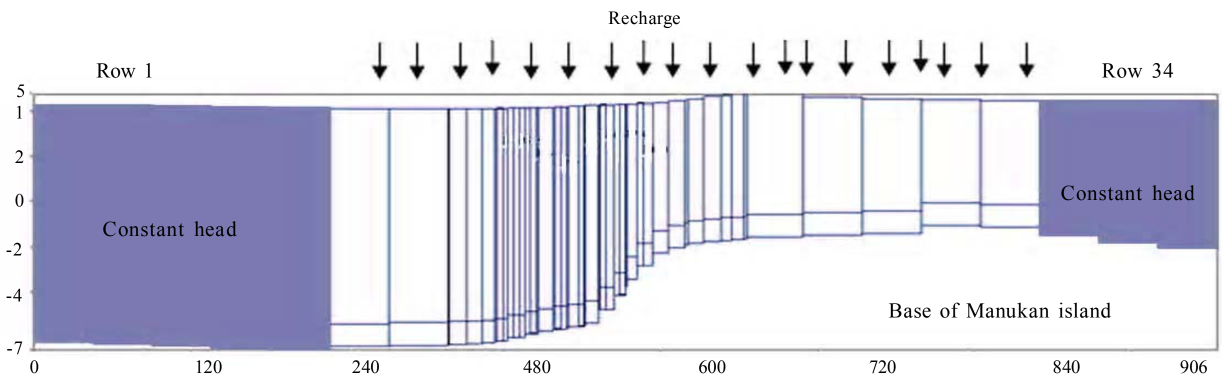


Fig. 2: Model grid and boundary conditions for Manukan Island

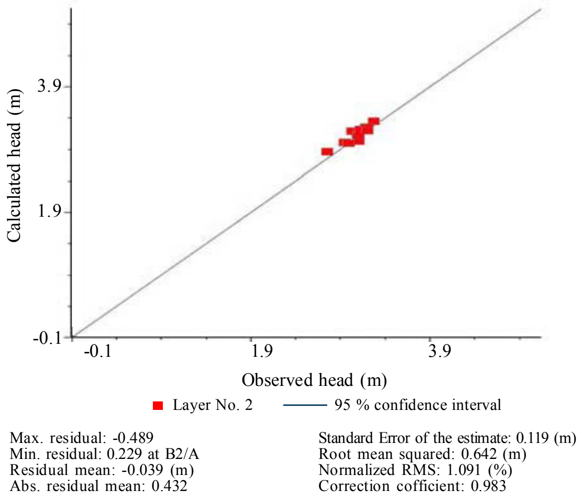


Fig. 3: Calibration fit for model calculated heads against observed heads at the end of simulations (March 2009) for 10 boreholes

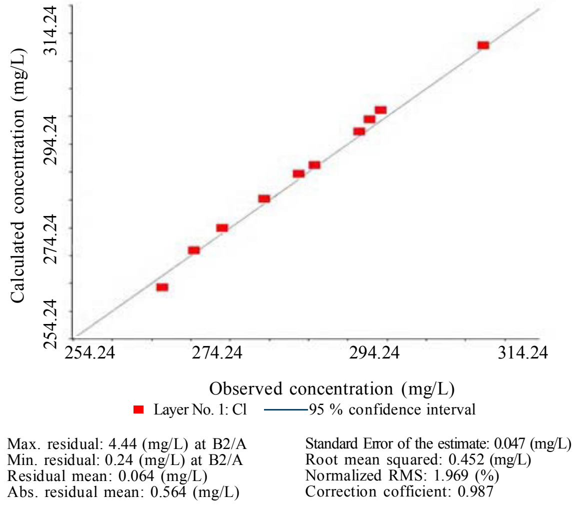
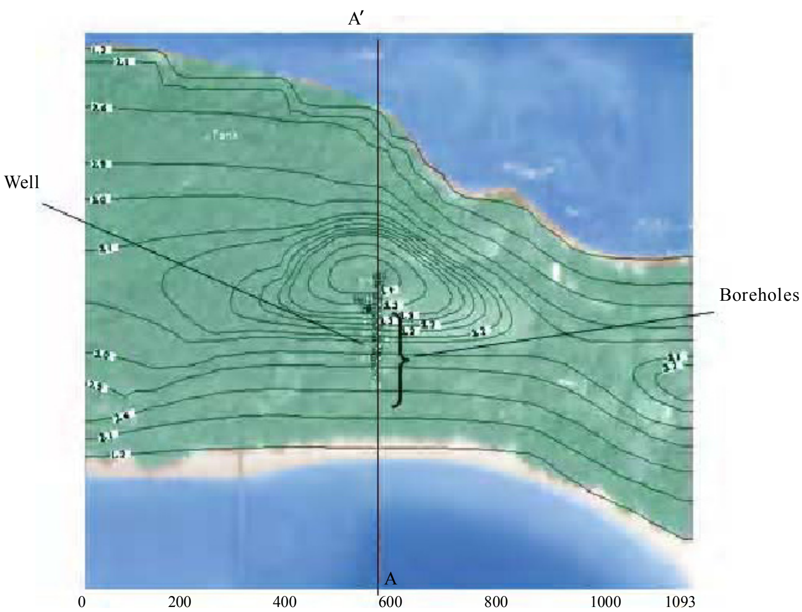


Fig. 4: Calibration fit for model calculated against observed chloride concentrations at the end of simulations (March 2009) for 10 boreholes



(Scale: Horizental: 1: 0.75; Vertical: 1: 0.75)

Fig. 5: Study area with a pumping well and boreholes locations

satisfactory degree at the end of simulation. It has been done in various groundwater modeling studies (Rejani *et al*., 2008).

Simulations of pumping rates and recharge rates

The calibrated and validated model could now be used for a variety management and planning studies. In predictive simulation, the parameters optimized during calibration are used to predict the system response to future events. Predictive simulations were performed to minimize the overexploration in the unconfined aquifer of Manukan Island (Table 2). The simulations were done to investigate the aquifer response towards climate change (recharge rate) and human pressures (pumping rate) on freshwater lens which have direct impacts on water resources and its management in this tropical small island. The output of these scenarios will be able to recommend the suitable groundwater management option in study area.

RESULTS AND DISCUSSION

Calibration and validation results

In this study model calibration is achieved through trial and error approach until the hydraulic heads and chloride values calculated by SEAWAT-2000 match the observed values to a satisfactory degree at the end of simulation. Model calibration is stopped at the end of the simulation when reasonable matches between the observed and calculated hydraulic head are achieved.

After each run, differences between simulated and observed heads were calculated with the goal of every difference being minimal. The residual between observed and calculated heads was used to calculate the root mean squared error (RMS) and the mean absolute error (MAE). As illustrated in Figs. 3 and 4, overall correlation coefficients of 0.983 and 0.987 were obtained for hydraulic heads and chloride concentrations. The model calibrations indicate a reasonably good match between observed and calculated hydraulic heads and chloride concentrations.Simulation modeling for different scenarios representing insights about the future changes in groundwater due to pumping and recharge rates

Groundwater flow in simulations 1 and 2

The results of the groundwater simulations under human pressure of island resources (pumping rate) and climate change (recharge rate) are shown in Table 3. Fig. 5 shows the study area with a pumping well and boreholes locations. The fluctuation of hydraulic heads in the island is influenced by recharge, pumping of groundwater, tidal, etc. (Hahn *et al.,* 1997).

At current pumping and recharge rates, hydraulic heads generally range from 3.4 to 2.1 m at flat low lying area. The high relief area acts as recharge area, the groundwater flow is directed downwards to low lying area. In order to demonstrate the effect of pumping scheme in study area, three pumpage schemes were selected in simulation 1. The first pumpage scheme (scenario A) was assumed to be at the current pumping and recharge rates in the study area. The second pumping scheme (scenario B) is to be 25 % less than the current rate. The third pumping scheme (scenario C) is to increase the current pumping rate by 25 % in order to meet the current tourist and water demand. The simulated values of hydraulic heads were from the pumping well (W1) to borehole nearest to sea (B1). It can be noticed that boreholes near to the pumping area (B6-B8) showed decreased in hydraulic heads level compared to boreholes which are far than pumping area (B1 or B10). Lowering the hydraulic heads in Manukan Island due to pumping will result the movement of the saline water into the aquifer (Shammas and Jacks, 2007). Current pumping rate was reduced by 25 % in order to protect and restore the groundwater resources in Manukan Island. The reduced pumping rate by 25 % was selected as the number of tourists plunged year by year, it is crucial to meet the demand of groundwater in the island. Reduced pumping rate by 25 % was acceptable range compared to other pumping rates in terms of groundwater management (Ong'or *et al.*, 2007). In Scenario B, the reduced pumping rate by 25 % increased the water level indicated by hydraulic heads. As the number of tourists boost year by year, the demand of groundwater pumping intensities were also expected to increase. With an increase of 25 % of current pumping rate (scenario C), it shows that the hydraulic heads became lower than pumping scheme in scenario A. This Fig. suggests a

Table 3: Simulated hydraulic heads from pumping well (W1) to borehole nearest to the sea

Hydraulic heads (m)	W1	B10	B9	B8	B7	B6	B5	B4	B3	B2	B1
Simulation 1 : Human pressures (Pumping Rate)											
Scenario A	2.1	3.0	3.4	3.3	3.2	3.1	3.0	2.8	2.6	2.5	2.2
Scenario B	2.7	3.1	3.5	3.3	3.3	3.2	3.1	2.9	2.7	2.5	2.2
Scenario C	1.9	2.9	3.3	2.9	2.8	3.0	3.0	2.7	2.5	2.4	2.2
Simulation 2: Climate change Impact (Recharge Rate)											
Scenario A	2.1	3.0	3.4	3.3	3.2	3.1	3.0	2.8	2.6	2.5	2.2
Scenario B	3.3	3.1	3.5	3.4	3.3	3.2	3.1	2.8	2.7	2.5	2.2
Scenario C	3.4	3.1	3.6	3.5	3.5	3.3	3.2	2.9	2.8	2.5	2.2

significant reduction of the future subsidence if the pumping rate was restricted in locations where pumping has been intensive. The decrease in the hydraulic heads in the well field area may lead to seawater intrusion due to pumping effect. In simulation 2, Table 2 shows the hydraulic heads levels at three different scenarios simulated in this study. The recharge rate increases the water level indicated by hydraulic heads levels (Scenario E). This shows that it can alter the bad effects of overdrafts in Manukan Island which has been suffering from an overexploration in its unconfined aquifer. The increased in hydraulic heads levels depends on the percentage reduction in pumping and recharge rates (Scenario F). It allows groundwater level increase hence addressing the environmental restoration issues with significant water volume stored within the given time limit. Even though 50 % reduction of pumping rate with an increased in recharge rate leads to gain in hydraulic heads levels but it is unacceptable. This is because there is need for tourism and domestic uses in this tourist island. A combination of reduction in pumping rate and increase in recharge rate in Scenario F (due to climate change), which embraces not only the quantity but also quality for both environmental

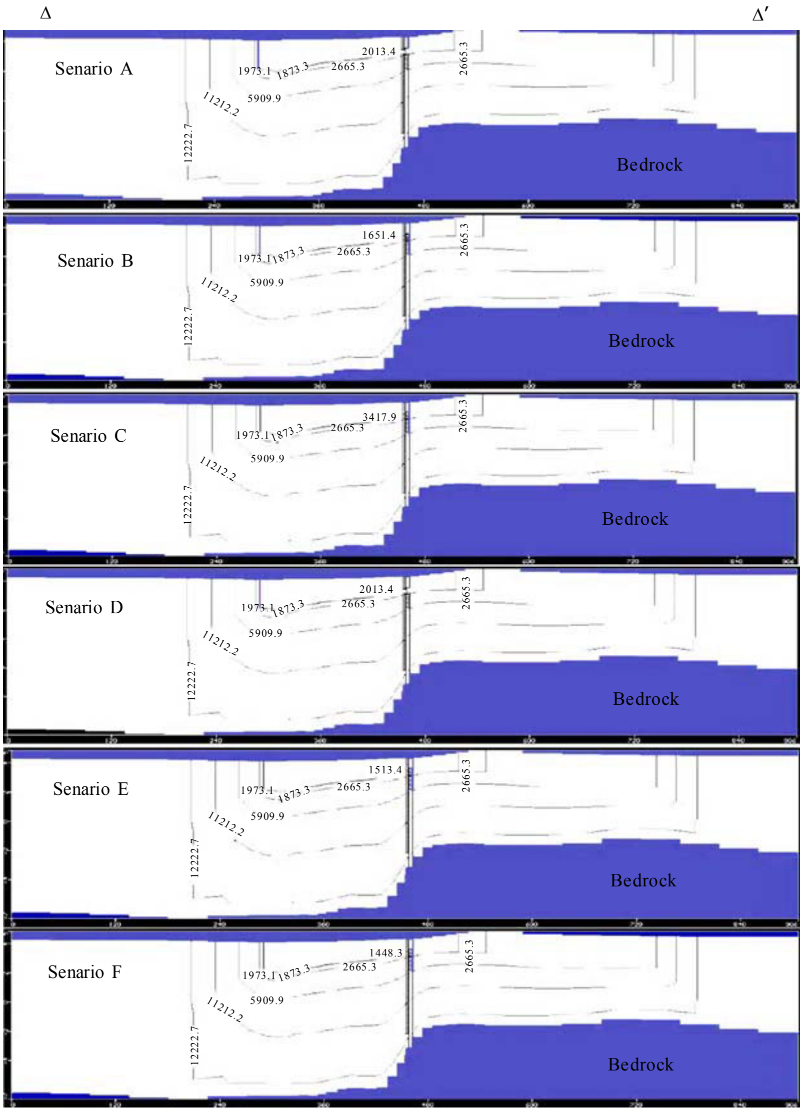


Fig. 6: Chloride concentrations simulations in different scenarios

restoration and island aquifer. Recent studies conducted by Chen and Hsu (2004) and Moustadraf *et al.* (2008) showed that groundwater level fluctuations have a strong correlation with climatic trends. According to IPCC (1997), groundwater recharge may increase in areas where heavy precipitations are major sources of groundwater recharge. Similarly in this study, the output showed the recharge rate increases water level indicated by hydraulic heads levels. However, according to Moustadraf *et al.* (2008), groundwater recharge is less efficient when the rainfall pattern is short and intense. Moreover, inconsistency in climate change in terms of precipitation influences the groundwater recharge. The chloride concentrations of the groundwater are important when dealing with controlling measurement of seawater intrusion is taken into account (Paniconi *et al.*, 2001). The study conducted by Paniconi *et al.* (2001) showed a strong and direct link between groundwater extraction and seawater intrusion. This is because decreased pumpage in the area has been considered as the main measure for controlling the effects resulting from groundwater withdrawal. Therefore, groundwater solute transport will be discussed in next subchapter.

Groundwater solute transport simulation

The chloride concentration in the studied aquifer at current pumping and recharge rates is 2013.4 mg/L. In simulation 1 (Fig. 6), the chloride concentration in pumping well was investigated at local scale within the vicinity of cone of depression. In simulation 1, scenarios B and C, the chloride concentrations decreased by 21.9 % and increased 69.8 %, respectively compared to scenario A. In simulation 2 (Fig. 3), scenarios E and F, the chloride concentrations decreased by 24.8 % and 28.1% respectively compared to scenario D. The chloride simulation showed that seawater in the lower most mixes with freshwater as the seawater migrates upward through vertical zone and laterally within the Manukan Island's aquifer toward pumping well. In general, reduction in pumping rate and an increase in recharge rate are capable to restore and protect the groundwater resources in Manukan Island.

In general, chloride concentrations in pumping well are far higher than the limit of World Health Organization (WHO) International Standard of 250 mg/L in pumping well especially in the cone of depression. The decreased in chloride concentrations due to reduction in pumping rate (25 %) with an increased in recharge rate can be attributed to the dilution of precipitated minerals, modifying its permeability by widening the pores/fractures allowing more water of lower chloride concentrations and diluting it (Ong'or *et al.* 2007). According to Samsudin *et al.* (2008), heavy rainfall that directly recharges the aquifer had flushed out most of the salts from the aquifer. Intergovernmental Panel on Climate Change (1997) stated that the effect of climate change such as in recharge rate will lead to adjustments in the global hydrological cycle which will affect the distribution of regional water resources. Sen (2008) explained that groundwater recharge mode is more sensitive to direct natural recharge. Direct natural recharge is marked as an increased of precipitation due to climate change. Many researchers believe that climate change mainly influences the groundwater recharge compare to vegetation and evapotranspiration. However, according to Intergovernmental Panel on Climate Change (1997), impact of climate change in recharge rate should also take into consideration of sea level rise impact. It is because the sea level rise impact of climate change may precipitate the intrusion of seawater into freshwater lens, reducing the quantity and quality of freshwater.

Groundwater sustainability impacted by climate change impacts (recharge rate) and human pressure (pumping rate)

Groundwater system in tourism islands such as in Manukan Island receives human and climate change pressures impacts. The present numerical simulations output were based on several scenarios on the aquifer system in the area. Seawater intrusion would be expected at the pumping well if the current rate (scenario A) of groundwater exploitation continues. Scenario C pumping scheme will worsen the current scenario of seawater intrusion. Thus, pumping scheme of scenario C will be eliminated from the consideration of the suitable groundwater management in this tropical small island. Thus, an alternative to eliminate pumping rate about 25 % could limit the seawater intrusion significantly about 21.9 % in pumping well concentration and reduced a clear large mixing zone was formed underneath the beach surface. Devlin and Sophocleous (2005) elobrated that recharge could affect the quality of the water in the aquifer thus also impacting associated ecological communities. However, water budget referring to the accounting of water in and out need to be identified to ensure the pumping scheme in scenario B will retain the sustainability of the freshwater in Manukan Island. Moreover at 25% reduced pumping with an increased in recharge rate (scenario F) seems to be the better risk option during wet season as it offers an optimum in terms of both water quality and quantity combined for the most visited tourist island, such in this study. It is worth noting that even though reduction about 50% inpumping rate with an increased in recharge rate will lead to reduction in chloride concentrations, the issue of environmental restoration can be achieved, but it is unacceptable. This is because there is need for tourism and domestic uses in this tourist island. Briefly, the Water Budget Myth idea is sustainable pumping must not exceed the recharge rate in a given aquifer (Bredehoeft, 2002). Consequently, efforts to measure recharge rates precisely are vital when an evaluation of sustainability is the objective.

Model limitation

The constructed three dimensional numerical model of unconfined aquifer of Manukan Island is strictly based on climate change (recharge rate) and human pressures (pumping rate). The considerations of sea level rise impact, temperature and evapotranspiration in future numerical model should be a focus. A computer modeling component to assess the behavior of the aquifer and its sustainable pumping rate is the preeminent way in any modern assessments of groundwater sustainability. New numerical model with more data as an input will capable to produce outputs which are more reliable for groundwater management.

CONCLUSION

A three-dimensional finite-difference numerical model has been developed for an understanding of groundwater sustainability under current aquifer conditions. The aquifer response due to recharge and pumping rates was successfully completed for Manukan Island. Simulations of six scenarios showed changes in hydraulic heads and chloride concentrations. At current pumping and recharge rates (scenario A), hydraulic heads generally range from 3.4 to 2.1 m at flat low lying area.It can be noticed that boreholes near to the pumping area (B6-B8) showed decreased in hydraulic heads level compared to boreholes which are far than pumping area (B1 or B10). Hydraulic heads (groundwater level) is the highest at the center of the island and decreases radially outward towards the coast in all the pumping schemes (scenarios B and C). Lowering the hydraulic heads in Manukan Island due to pumping will result the movement of the saline water into the aquifer by the lateral and upward invasion of the seawater to the aquifer (scenario C). Reduced pumping rate by 25 % (scenario B) was acceptable range compared to other pumping rates in terms of groundwater management, increases the water level indicated by hydraulic heads levels. The recharge rate (scenarios E and F) increases the water level indicated by hydraulic heads levels. This shows that it can alter the bad effects of overdrafts in Manukan Island which has been suffering from an overexploration in its unconfined aquifer. This simulation showed that with an increased in recharge rate allows groundwater level increase hence addressing the environmental restoration issues with significant water volume stored within the given time limit. The chloride concentration in the studied aquifer at current pumping and recharge rates is 2013.4 mg/L (scenarios A and D). In simulation 1, scenarios B and C, the chloride concentrations in pumping well decreased by 21.9 % and increased 69.8 % respectively compared to scenario A. In scenarios E and F of simulation 2, the chloride concentrations decreased by 24.8 % and 28.1 % respectively compared to scenario D. In general, reduction in pumping rate and an increase in recharge rate are capable to restore and protect the groundwater resources in Manukan Island. Thus, in the consideration of Manukan Island groundwater management options, scenario B is very much essential to lessen the seawater intrusion and sustain water resources on a long-term basis whereas the selection of scenario F is the preeminent option during wet season in Manukan Island. In the future, as new data become available, the model should be updated periodically to refine estimates of input parameters values and simulate new management options. The output of this study is a foundation which can be used in any tropical small islands aquifers in order to protect the water resources.

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