NUMERICAL MODELING OF SEAWATER INTRUSION IN THE AQUIFER OF MANUKAN ISLAND

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ABSTRACT

NUMERICAL MODELING OF SEAWATER INTRUSION IN THE AQUIFER OF MANUKAN ISLAND

This study presents an understanding of seawater intrusion in the low lying area of Manukan Island. A three dimensional numerical model (SEAWAT-2000) was developed based on modeling protocol using low lying area of Manukan Island. SEAWAT-2000 output indicated that there is about 1.4% of freshwater and seawater mixing ratio at sea level in low lying area of Manukan Island illustrates the seawater intrusion problem. Upconing process simulated by SEAWAT-2000 showed the current status of seawater intrusion in Manukan Island is about 14.6% of freshwater and seawater mixing ratio at the beneath of pumping well (W6). Moreover, the calibrated model was also used to predict current and potential extent of seawater intrusion in low lying area of Manukan Island two years with all conditions assumed to remain same as those in December 2009 under different scenarios of varying recharge and pumping rates. The SEAWAT-2000 model's output showed pumping rates are higher than recharge rates in all of the selected scenarios, thereby indicating that overpumping is the main factor behind seawater intrusion in the low lying area of Manukan Island. The seawater-freshwater mixing ratio moves landwards after two years of simulation in Scenario 1. In order to control overpumping in this study area, Scenario 2 has resulted in backward movement of the 1.4% seawater-freshwater mixing ratio towards to coast after two years of prediction. The current contamination of the coastal aquifers by seawater intrusion will be more severe with an impact of El-Nino events on groundwater resources depletion in Scenario 3. Reductions of pumping and recharge rates in Scenario 4 have worsened seawater intrusion problem. With an aid of artificial recharge, highest hydraulic heads and lowest chloride concentration were observed (Scenario 5). In addition to this, water balance components have illustrated sustainable groundwater management selected for Manukan Island's current situation will be Scenario 2. In view of the effects of El-Nino events in the future, Scenario 5 can be implemented to restore groundwater resources. Moreover, a suitable groundwater management plan in Manukan Island must also include economic, social and environmental issues together with further adjustment of pumping rate using water usage data from various parts (restaurant, tourism, office and chalets).In a nutshell, this study has provided a management foundation for restoration of the groundwater resources of Manukan Island which can be applied in other small islands with similar hydrogeological conditions..

Keywords: groundwater, seawater intrusion, SEAWAT-2000, recharge, pumping, management

ABSTRAK

Kajian ini adalah mengenai kemasukan air laut di kawasan rendah, Pulau Manukan. Peraga berangka tiga dimensi (SEAWAT-2000) telah dibina berdasarkan protokol permodelan menggunakan kawasan rendah di Pulau Manukan. Output peraga berangka SEAWAT-2000 mendapati bahawa nisbah percampuran air tawar dan laut di kawasan rendah Pulau Manukan adalah sebanyak 1.4%. Simulasi proses "upconing" menunjukkan nisbah percampuran air tawar dan laut di telaga pam (W6) adalah 14.6%. Tambahan, peraga berangka yang telah TERkalibrasi digunakan untuk meramal potensi lanjut proses percampuran air tawar dan laut di kawasan rendah Pulau Manukan bagi dua tahun berikutnya dengan keadaan yang sama seperti pada bulan Disember 2009 berdasarkan senario kadar pengisian semula dan pengepaman yang berbeza. Output peraga berangka SEAWAT-2000 menunjukkan kadar pegepaman adalah lebih tinggi dari kadar pengisian bagi semua senario yang dikaji menerangkan pengepaman yang berlebihan adalah faktor utama di sebalik kemasukan air laut di kawasan rendah Pulau Manukan. Nisbah percampuran air tawar dan laut bergerak ke arah daratan setelah dua tahun di dalam Senario 1. Bagi mengawal pengepaman yang berlebihan di kawasan kajian, Senario 2 telah menghasilkan pergerakan nisbah percampuran air tawar dan laut ke arah lautan. Kemasukan air laut pada masa ini dijangka akan diterukkan lagi oleh impak El-Nino terhadap sumber air bawah tanah. Pengurangan kadar pengepaman serta pengisian semula juga telah mengeruhkan lagi keadaan kemasukan air laut (Senario 3). Pengurangan kadar pengepaman dan pengisian semula dalam Senario 4 telah memburukkan lagi keadaan. Dengan bantuan pengisian semula secara buatan, paras hidraulik yang tertinggi serta kepekatan klorida yang terendah telah dikenalpasti (Senario 5). Tambahan, komponen neraca air telah menggambarkan penggunaan serta pengurusan sumber air bawah tanah secara lestari di kawasan kajian ini pada masa sekarang adalah Senario 2. Dengan kesan El-Nino yang dijangkakan pada masa hadapan, Senario 5 boleh dilaksanakan bagi melindungi bekalan sumber air bawah tanah di Pulau Manukan. Tambahan, pelan pengurusan sumber air bawah tanah yang sesuai di Pulau Manukan harus merangkumi isu ekonomi, sosial dan alam sekitar serta, penyesuaian kadar pengepaman lebih lanjut boleh dilakukan dengan menggunakan data penggunaan air dari pelbagai bahagian (restoran, pelancongan, pejabat dan rumah tumpangan). Kesimpulannya, hasil kajian ini telah memberikan asas pengurusan bagi perlindungan sumber air bawah tanah di Pulau Manukan. Ia boleh diaplikasi di pulau-pulau kecil yang mempunyai keadaan hidrogeologikal yang serupa bagi tujuan perlindungan sumber air bawah tanah.

***Kata kunci**: air bawah tanah, kemasukan air laut, SEAWAT-2000, pengisian semula, pengepaman, pengurusan*

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LIST OF ABBREVIATIONS

IPCC	Intergovernmental Panel on Climate Change
REV	Representative Elementary Volume
SUTRA	Saturated-Unsaturated Transport
CODESA3D	COupled variable DEnsity and Saturation 3D
PVC	Polyvinyl Chloride
APHA	American Public Health Association
ORP	Oxygen Reduction Potential
WHO	World Health Organization
MOH	Ministry of Health
USEPA	U.S. Environmental Protection Agency
IGWMC	International Ground Water Modeling Center
TVD	Total-variation-diminishing
ET	Evapotranspiration
MOC	Method of Characteristics
MMOC	Modified Method of Characteristics
PCG2	Preconditioned Conjugate-Gradient Package
SIP	Strongly Implicit Procedure Package
SSO	Slice-Successive Overrelaxation Package
SAMG	Algebraic Multigrid Methods for Systems
GMG	Geometric Multigrid Solver
UFD	Upstream Finite Difference
CFD	Central Finite Difference
GCG	Generalized Conjugate Gradient Solver

ME	Mean Error
MAE	Mean Absolute Error
RMS	Root Mean Squared Error
GUI	Graphical User Interface
SI	International System Of Units
3D	Three Dimensional
2D	Two Dimensional

LIST OF SYMBOLS

EC	Electrical conductivity
Sa	Salinity
TDS	Total dissolved solids
Cl	Chloride
km	Kilometer
cm	Centimeter
m	Meter
Ca^{2+}	Calcium
Mg^{2+}	Magnesium
HCO_3^-	Bicarbonate
Na^+	Sodium
K^+	Potassium
SO_4^{2-}	Sulphate
^oC	Celcius
%	Percentage
km^2	Square kilometer
mL	Mililiter
mg	Miligram
mg/L	Milligram/liter
N	North
E	East
^{o}	Degree
K_2CrO_4	Potasium dichromate
$AgNO_3$	Argentum nitrate
AgCl	Silver chloride
Ag_2CrO_4	Silver chromate

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CHAPTER 1

INTRODUCTION

1.1 Islands Definition

Islands present in different manners and patterns, located adjacent to continental masses and some are dispersed in midocean in singular isolation or in groups. Many islands are arranged, geographically in quadrangles, triangles and various patterns (Munawwar, 1995). Islands can be categorized in a number of ways, each for useful purposes. However there is no single definition fits all the purposes (Hassan et al. 2005). Most of available definitions on islands tend to incorporate with size, topography and geology (Figure 1.1). In term of size, large islands are considered as an area of 13, 000-20, 000 square kilometers with fewer than 1.0-1.2 million people. Small islands are considered to be 10, 000 square kilometers and have 500, 000 or less people. Definitions of very small, micro and smallness also have been used in islands definitions (Falkland, 1991; Hassan et al. 2005).

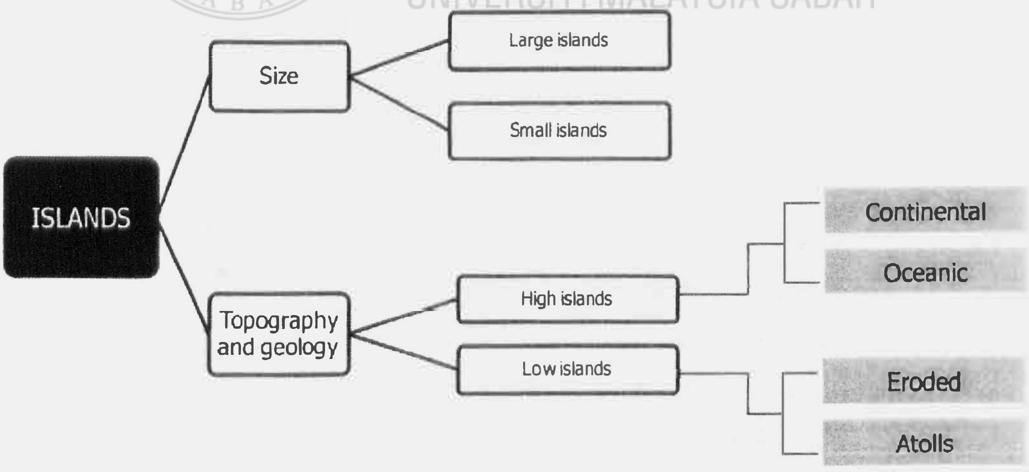

Figure 1.1: Islands Definition

Source: Falkland (1991)