NITRATE-NITROGEN CONCENTRATION VARIATION IN GROUNDWATER FLOW IN A PADDY FIELD

(Date received: 1.12.2009/ Date approved: 20.8.2010)

Mohamed Azwan Mohamed Zawawi[1], Mohd Kamil Yusoff[2], Hazilia Hussain[3] and Suhani Nasir[4]

[1,4]Faculty of Engineering, Universiti Putra Malaysia,
43400 UPM, Serdang, Selangor
[2]Faculty of Environmental Studies, Universiti Putra Malaysia,
43400 UPM, Serdang, Selangor
[3]Faculty of Health Sciences, Universiti Technologi MARA,
42300 UiTM, Bandar Puncak Alam, Selangor
E-mail: [1]azwan@eng.upm.edu.my

ABSTRACT

This study was carried out to evaluate the influence of groundwater on nitrate-nitrogen concentration in a paddy field. Fertiliser if applied excessively can cause leaching into the soil and will penetrate deep into the soil and eventually contaminate the groundwater. Nitrates in groundwater is soluble hazardous to users. This work was carried out at Ladang Merdeka Ismail Mulong, Kota Bharu, Kelantan to determine groundwater and nitrate-nitrogen flow using ArcGIS in a Geographical Information System (GIS) environment to produce groundwater level and nitrate concentration variation maps. All data were obtained from field measurements. The results showed that the average nitrate level was 4.81 mg/l with a maximum value of 17.16 mg/l. The groundwater levels in this area ranged from 3.75 to 6.52 meters above mean sea level with an average of 5.65 meters. Three dimensional images of ground surface and groundwater levels variation were also produced to study the relationship between groundwater and nitrate movement. From the analysis, it can be deduced that the groundwater and nitrate generally flows from the South-West to the North-East direction following the ground surface gradient.

Keywords: *GIS, Groundwater, Nitrate-nitrogen, Paddy Field*

1.0 INTRODUCTION

Many regions around the world are dependent on groundwater resources for their various uses especially in rural areas. Major threats to groundwater quality are from point sources and non-point sources. These could be due to urbanisation (septic tanks, sewer and detergent), industrial wastewaters and agricultural activities (fertilisers and pesticides). Contamination of groundwater can result in poor drinking water quality. Many studies have reported growing incidences of nitrate pollution and increase of nitrate concentration in groundwater in intensive farming areas. The main source of nitrate contamination is nitrogen rich fertilisers [1], [2], [3].

In Kelantan, Malaysia, groundwater plays a very important role in the public water supply system. About 70% of the total water supply in the state is derived from groundwater [4]. The shallow aquifer system in the Kelantan river delta constitutes an important source of water not only for public water supply, but also for domestic and agricultural purposes [4]. Being shallow and relatively unprotected, the aquifer is generally exposed to higher risk of contamination due to anthropogenic activities at the surface.

In a study conducted by Abdul Rashid [5], the result showed that 35 percent of the areas around the Kelantan River Valley included Kota Bharu, Bachok, Tumpat and Pasir Mas district have nitrate levels exceeding the threshold value, 10 mg/L while 2 percent exceeds 45mg/L or the permissible World Health Organisation (WHO) value. Generally, groundwater with elevated nitrate content appears to be related to areas with cultivation [5].

The large transmissivity value of about 2,000 to 24,000 m^2/day and permeability value of about 700 to 2,200 m/day can easily cause the surface pollutants to infiltrate into the shallow aquifers through precipitation, infiltration, stream infiltration or waste drainage system at the surface or from the water supply leakage [4]. In Kelantan, the climate changes are obvious and produce significant impacts on groundwater levels which also contribute towards the contamination of groundwater in the shallow aquifers [4].

Apart from the climatic changes, pumping activities for supplying groundwater can also contribute to the movement of groundwater. In a populated area where the demand for groundwater is high, extensive pumping will cause the water level to decline lower than the surrounding area. The differences in the water table will eventually cause the movement of groundwater. The groundwater movement would contribute to the variation of the contaminant. A study in France showed that changes in the physical-chemical groundwater quality occurred at an hour-scale in deep sediments due to flooding and pumping [6].

Nitrate, being one of the major contaminants in groundwater may be hazardous when it is consumed excessively. Studies have shown that high nitrate levels are associated with diseases such as methemoglobinemia, gastric cancer, non-Hodgkin's lymphoma and diarrhea [7-9].

In this study, satellite images and groundwater data from a paddy field at Ladang Merdeka Ismail Mulong, Kelantan were assembled in a GIS environment to achieve three main objectives as follows:

(i) to evaluate the groundwater level variation
(ii) to determine the general groundwater flow and
(iii) to evaluate the concentration and the variation of nitrates in groundwater.

2.0 MATERIALS AND METHODS

2.1 The Study Area

Kota Bharu is a district in Kelantan, consisting of a total area of about 14,922 square kilometers. It is the state's administration and commercial centre. Kelantan's climate is tropical monsoon, with stable temperatures ranging from 21°C to 32°C. Dry and warm weather with consistently high humidity on the lowlands ranging from 82% to 86% are seen through January to April. It has an average yearly rainfall of 2,540 mm, with the wettest months being from November through January

The study site is known as the Ladang Merdeka Ismail Mulong. It is situated in Kampung Mulong Lating, Kota Bharu. The approximate longitude and latitude of the study area is 668000N to 671000N and 472000E to 473000E. Ladang Merdeka Ismail Mulong is currently the largest in the Kemubu Agricultural Development Authority (KADA) area. It is a result of a systematic management of paddy fields introduced by KADA by combining smaller paddy lots into one large and uniformly distributed paddy field.

2.2 Field Measurements

All the data required were obtained from field measurements. The field measurements include sampling, analyzing, leveling, and GPS readings. Geographic locations or the coordinates of the wells were obtained using E-Trex Garmin hand-held Global Positioning System (GPS). The GPS uses the World Geodetic System of 1984 (WGS 84) reference system which provided the coordinates of the wells in the form of degrees, minutes and seconds (d.m.s). These d.m.s coordinates were converted into meters East and North because the image provided by Malaysian Centre for Remote Sensing (MACRES) uses the RSO coordinate system. This conversion was done using the GPS Pathfinder software which automatically calculate and convert the d.m.s coordinates into meters East and North.

Leveling was carried out to obtain the surface level of the study area above mean sea level (a.m.s.l). The leveling process includes all the monitoring wells and also the production wells. The measurements of the surface levels of monitoring wells in the paddy fields were taken from inside of the paddy plots and for the production wells, measurements were taken from the ground surface.

Groundwater levels in the wells were obtained by using the combination procedures of leveling and water level measurement from the ground surface with a water level indicator. The water samples were analysed within 48 hours for nitrate-nitrogen using a spectrophotometer (DR 2500, Hach Co.) after reduction with cadmium [10].

2.3 GIS Data and Analysis

The raster image obtained from MACRES was a multispectral image with resolution of 10 meters taken with Spot 5 satellite. The raster image was used as the base map in GIS analysis using ArcGIS. The image was already georeferenced with Rectified Skew Orthomorphic (RSO) coordinate system. RSO is a local plane projection system frequently used in Malaysia because it provides the geographic location in the form of meters of Easting and Northing. Since the map has been georeferenced, it was digitized on-screen to create point, segment, and polygon maps of the different geographical entities. The locations of the monitoring wells were digitised as points and linked to an attribute table, including all the water levels and chemical data (nitrate-nitrogen levels). The entities that were digitised include the paddy field, main canal, sub canals and the nearest populated site around the paddy field. To investigate the spatial extent of groundwater level and nitrate concentration level, a groundwater variation map and a nitrate concentration map were constructed from the point data using Kriging interpolation [3].

In Kriging, a weighted averaging on point values were performed where the output estimates equal the sum of product of point values and weights divided by the sum of weights [3]. The weight factors in Kriging were determined by using a user-defined semi-variogram model based on the output of a spatial correlation operation and the distribution of inputs points [3]. These values that are needed to perform the Kriging analysis can be obtained by using the GS+ software. The output raster map that was obtained from the Kriging analysis showed the estimation of groundwater levels and nitrate concentration in the study area. From these maps, the groundwater flow behavior can be determined.

Three dimensional images analysis of ground surface level variation and groundwater level variation were compared to investigate the relationship between groundwater and nitrate-nitrogen movement.

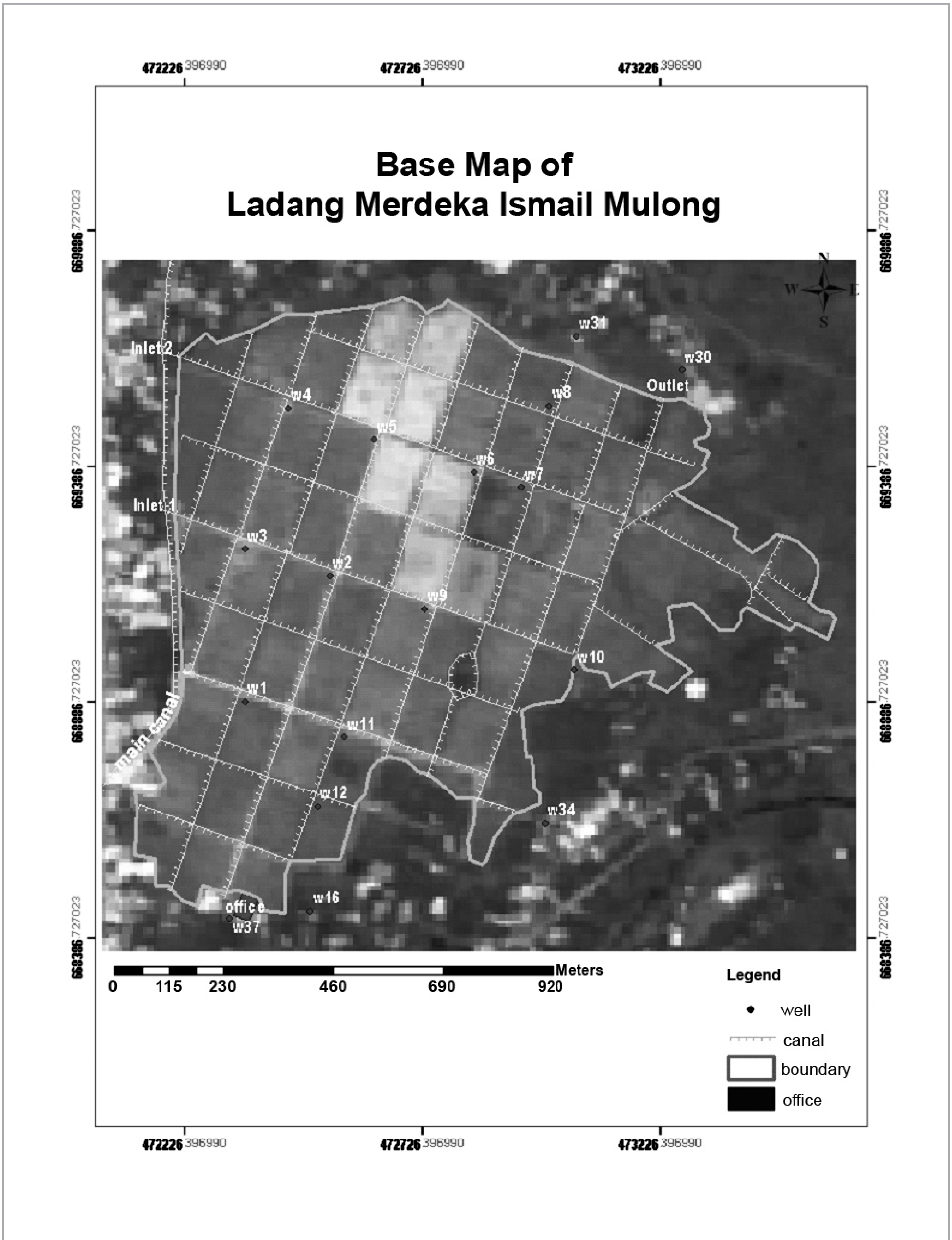

Figure 1: Base Map of Ladang Merdeka Ismail Mulong

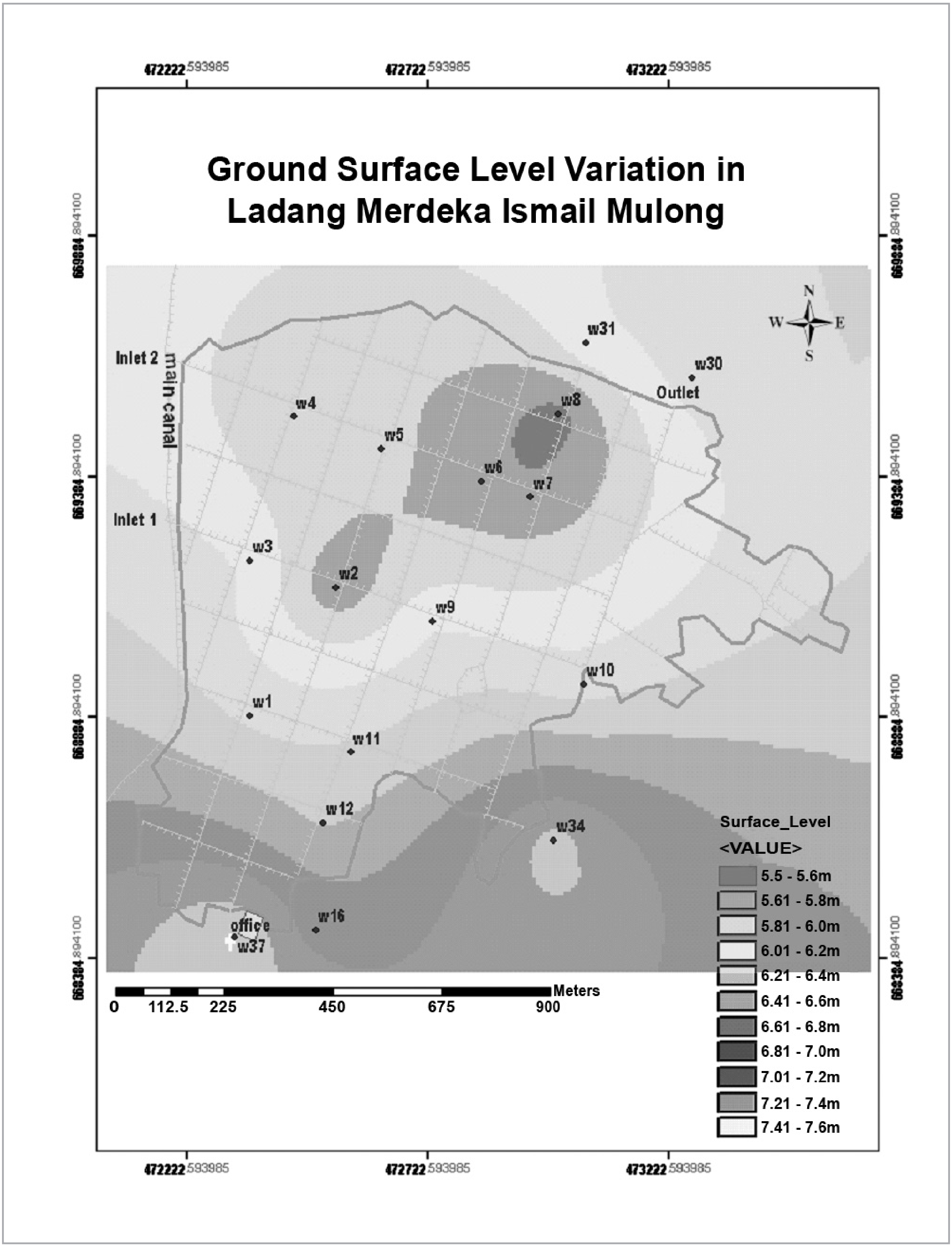

Figure 2: Ground Surface Level Variation in Ladang Merdeka Ismail Mulong

3.0 RESULTS AND DISCUSSION

3.1 Base Map of Ladang Merdeka Ismail Mulong

The base map in Figure 1 shows the location of the monitoring wells, the paddy field boundary, the field's office and also the main canal and sub canals of the study area. There were a total of twelve monitoring wells in the paddy field and four production wells in the population area around the paddy field. The four production wells represented two villages around the paddy field. W37 and W34 in the South East represent Kampung Lanting and W30 and W31 in the North-East represents Kampung Tunjung Dalam. The map also indicates the inlets and outlet of the surface water. There are two inlets from the main canal into the paddy field and an outlet from the paddy field. The flow of the surface water in the paddy field is from the North-West to the North-East direction.

3.2 Ground Surface Level Variation in Ladang Merdeka Ismail Mulong

From the ground surface level variation, it can be observed that the area around W37 in Kampung Lanting at the South East of the study area had the highest ground surface level, which was 7.41 to 7.60 meters above mean sea level (Figure 2). The ground surface levels decreases in the North -East direction and towards the confines of the paddy field. The lowest value of 5.50 to 5.60 meters above mean sea level was observed around W8 in the paddy field. The areas outside the paddy field have a higher ground surface level compared to the area inside the paddy field. This could be explained because the measurement of the surface level in the paddy field was referenced from within the paddy plot.

Figure 3 represents the three dimensional image of ground surface level variation with the brighter areas indicative a higher surface level while the darker areas are the lower surface levels. W37 and W34 in Kampung Lanting have the highest surface levels and W2 and W8 in the paddy field were areas with the lowest surface levels. W30 and W31 in Kampung Tunjung Dalam are having relatively low surface level.

3.3 Groundwater Level Variation in Ladang Merdeka Ismail Mulong

The map in Figure 4 shows the groundwater level variation in Ladang Merdeka Ismail Mulong. Areas around W37 and W16 (Kampung Lanting) are the areas with the highest groundwater level, which was 6.41 to 6.60 meters above mean sea level. The groundwater levels decrease towards the North East, similar to the ground surface levels. The groundwater flows from the paddy field to Kampung Tunjung Dalam because of the hydraulic gradient which decreases towards the village. Kampung Tunjung Dalam had the lowest groundwater level of 3.70 to 3.80 meters above mean sea level. Thus the general direction of groundwater flow was from the South- West to the North- East.

The arrows in the three dimensional image of groundwater level variation (Figure 5) shows the general direction of groundwater flow. From the image, it can be clearly seen that the groundwater decreases from W37 and W16 in Kampung Lanting towards W30 and W31 in Kampung Tunjung Dalam. The groundwater flows from Kampung Lanting through the paddy field towards Kampung Tunjung Dalam.

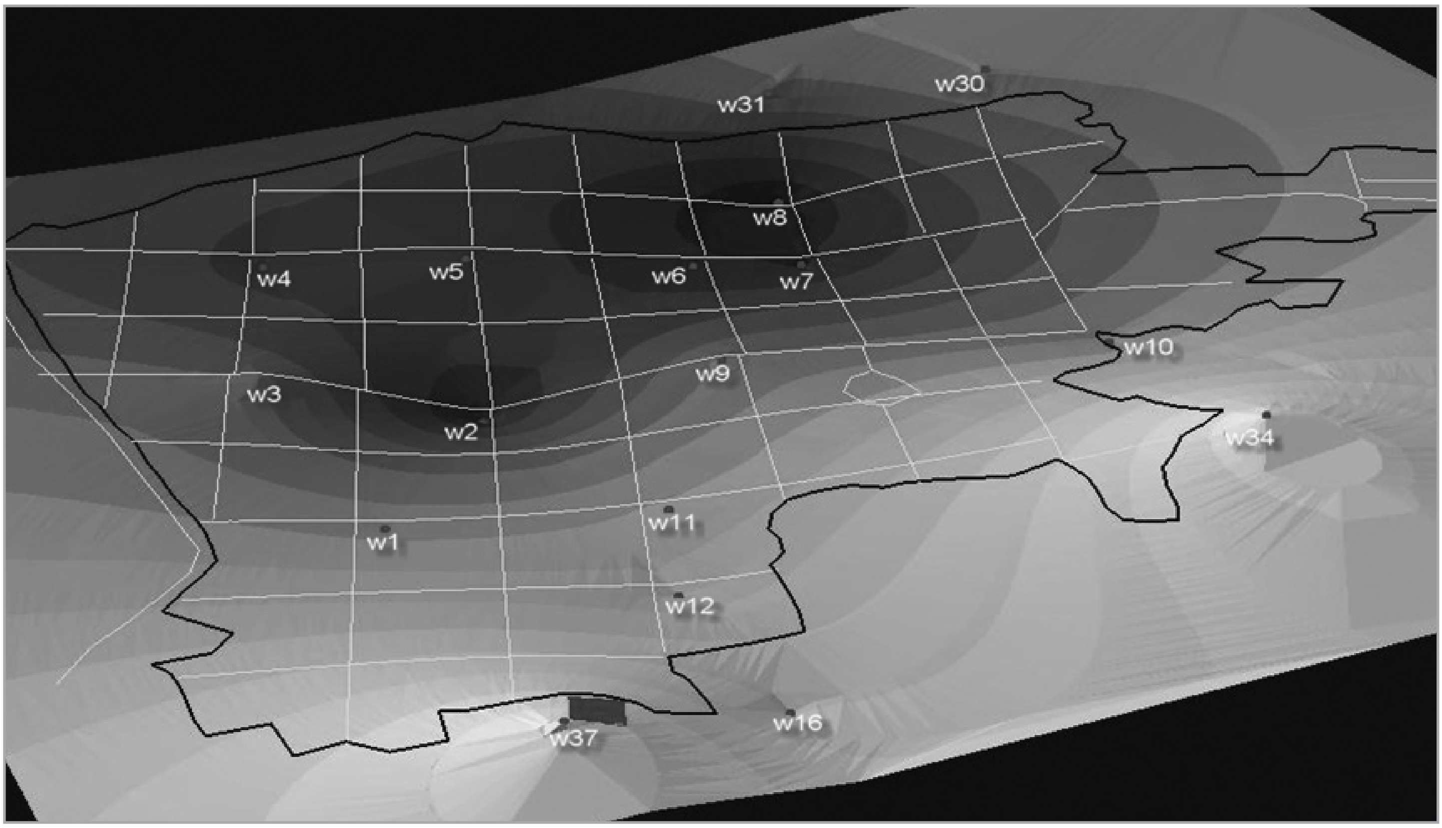

Figure 3: 3D Image of Ground Surface Level Variation

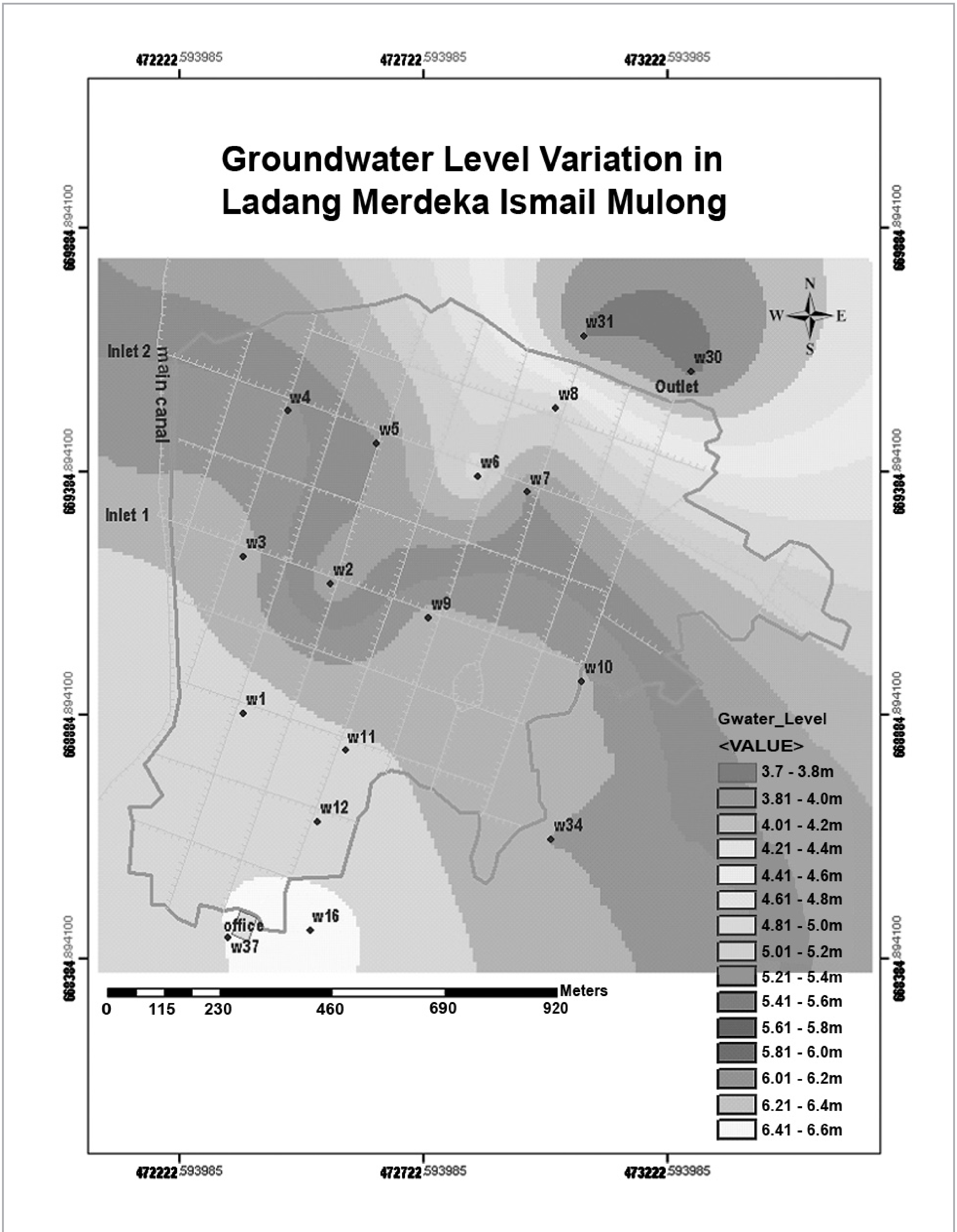

Figure 4: Groundwater Level Variation in Ladang Merdeka Ismail Mulong

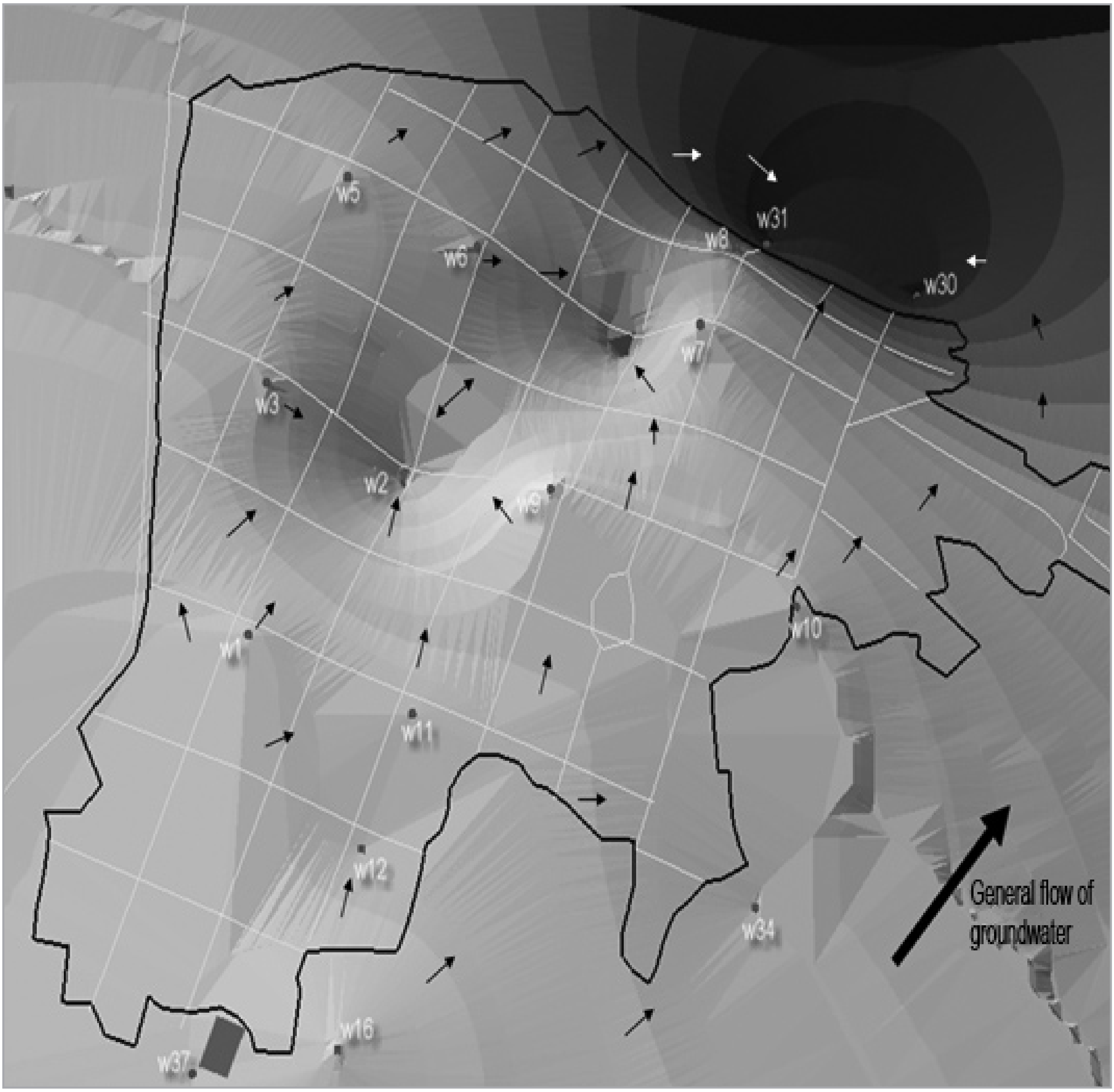

Figure 5: 3D Image of Groundwater Level Variation

3.4 Nitrate Level Variation in Ladang Merdeka Ismail Mulong

Examination of the pattern of nitrate concentration clearly showed that it was similar to the direction of the groundwater flow (Figure 6). Thus, since the groundwater level in Kampung Lanting is high and its movement is towards the paddy field, the nitrate level inside the paddy field turns out to be higher than in the Kampung Lanting. The highest nitrate level was around W12 with a value of 17.16 mg per liter.

The abrupt increase of nitrate concentration around W12 may indicate an introduction of nitrate from other sources. It could be associated with leakage of fertilisers stored at the KADA office located in the South East which percolates into the soil and later into the groundwater. However, the increase of nitrate concentration may also be contributed from septic tanks, sewage wastes, animal wastes and organic matters from the village in Kampung Lanting. This matter has to be further investigated.

The groundwater level in Kampung Tunjung Dalam was lower than inside the paddy field. This relates well with the areas around this village having a considerable high nitrate concentration which is 13.64mg/L. The groundwater flows from higher to lower areas carrying the contaminants which accumulate around these areas. The nitrate contamination most likely could have come from the nitrogen fertilisers applied to the rice crop.

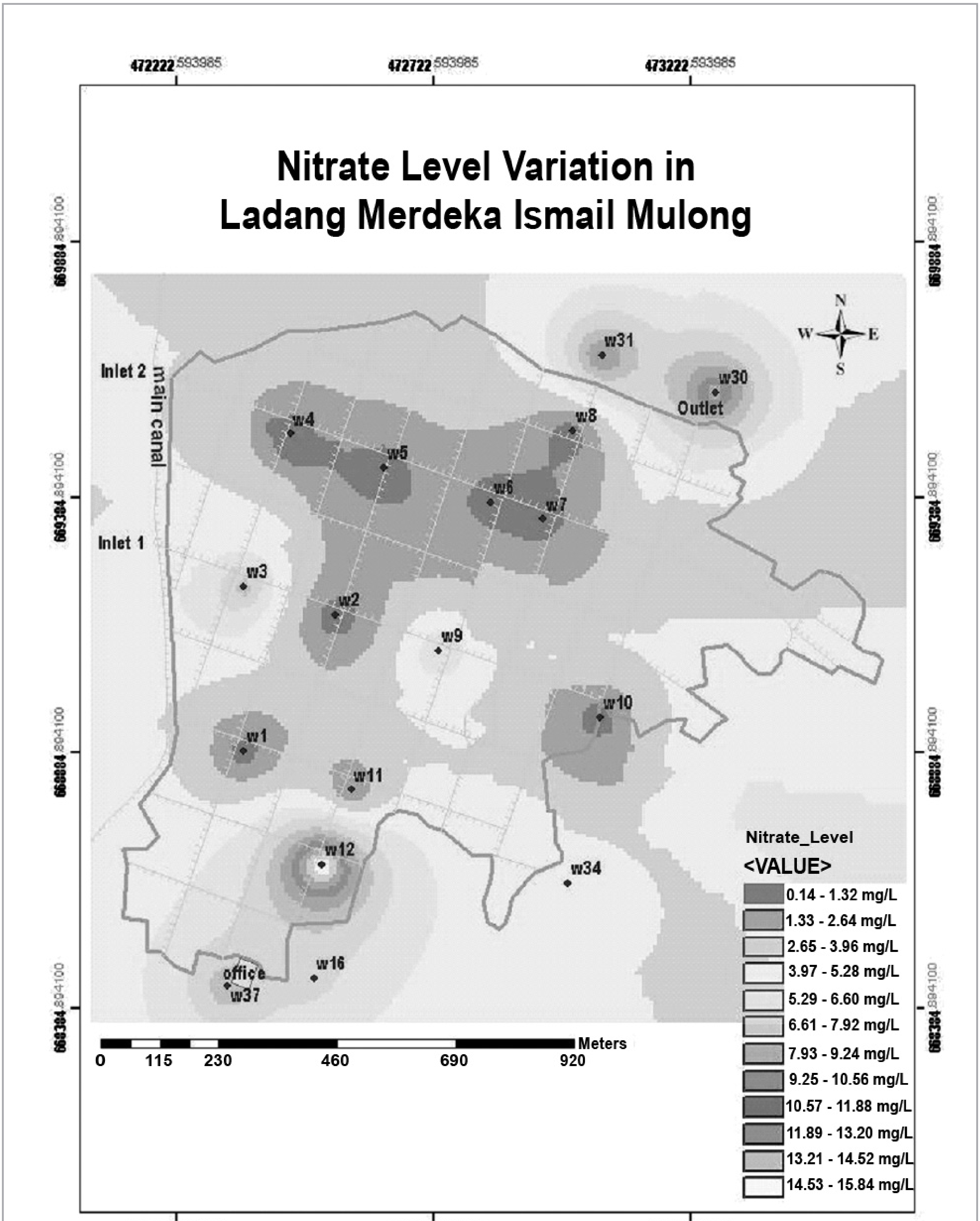

Figure 6: Nitrate Level Variation in Ladang Merdeka Ismail Mulong

In the paddy field, the nitrate levels variation was non uniform. In general, the nitrate levels in the paddy field were quite low. Time could be the factor because at the time of samplingthe nitrogen from the fertiliser has not percolated into the groundwater yet.

3.5 Correlation between Groundwater and Nitrate Flow

The nitrate level variation showed a similar pattern to the direction of groundwater flow which was from the South-West to the North-East. However, this observation does not apply to the inside of the paddy field because the nitrate concentration variation was not uniform.

4.0 CONCLUSION

The variation of groundwater level and the nitrate concentration in groundwater was successfully shown through the maps produced by using ArcGIS and Kriging interpolation. The flow of groundwater and nitrate-nitrogen in groundwater were determined by analysis of these maps. The results suggested that nitrate concentration variation corresponds to the groundwater flow, that is, from higher surface level to lower surface level in the direction from the South-West to the North-East. ■

REFERENCES

[1] Pacheco, J., Martin, L., Cabrera, A., Steinich, B. and Escolero, O. (2001). Nitrate temporal and spatial patterns in 12 water-supply wells, Yutacan, Mexico. *Environmental Geology* 40 :708-714.

[2] Thornburn, P.J. Biggs, J.S., Weier, K.L. and Keating, B.A. (2002). Nitrate in groundwater of intensive agricultural areas in coastal Northeastern Australia. *Agriculture Ecosystems and Environment* (94: 49-58).

[3] Babiker, I.S., Mohamed, M.A.A., Terao, H., Kato, K. and Ohta, K., (2004). Assessment of groundwater contamination by nitrate leaching from intensive vegetable cultivation using GIS. *Environment International* 29 :1009-1017.

[4] Safeen and Azmi (1998). *Variation and Nitrate Levels in Groundwater in Kelantan River Valley*. Geological Survey Department Malaysia.

[5] Abdul Rashid Bachik (1994). *Variation and Nitrate Levels in Groundwater in Kelantan River Valley*. Geological Survey Department Malaysia.

[6] Mauclaire, L. and Gilbert, J. (1998). Effects of pumping and floods on groundwater quality: a case study of the Grand Gravier well filed (Rhone, France). *Hydrobiologica* 389:141-151.

[7] Freedman, D. Michal, Cantor, Kenneth P., Ward, M. H. and Helzsouer, K. J. (2000). A Case-Control Study of Nitrate in Drinking Water and Non-Hodgkin's Lymphoma in Minnesota. *Archives of Environmental Health* 55(5) :326-329.

[8] Gupta , S. K., Gupta, R. C., Gupta, A. B., Seth, A. K. and Jagdesh, K. (2001). Recurrent Diarrhea in Chidren in Areas with High Levels of Nitrate in Drinking Water. *Archives of Environmental Health* 56(4): 369-373.

[9] FewtrellL.(2004).Drinkingwaternitrate,methemoglobinemia, and global burden of disease: a discussion, *Environmental Health perspective* 112: 1371-1374.

[10] American Public Health Association. (1998). Standard methods for the examination of water and wastewater, Twentieth edition, New York.

PROFILES

MOHAMED AZWAN MOHAMED ZAWAWI is a lecturer in Department of Biological and Agricultural Engineering, Faculty of Engineering, University Putra Malaysia. His research interests include Groundwater, Water Resources Engineering and Soil and Water Engineering. He teaches several courses such as Groundwater Hydrology, Soil Engineering, Bio-Environment System and Water supply Engineering.

MOHD. KAMIL YUSOFF is a General Manager of UPM Holdings, Universiti Putra Malaysia. He also works as a lecturer in Department of Environmental Science, Faculty of Environmental Studies, Universiti Putra Malaysia specializes in Hydrology, Water Quality, Soil Erosion and Plant Water Stress.