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Original Research Article

Nitrate concentration in groundwater wells as pollution indicator in Yarmouk River Basin using SWMS-3D Model: A case study/ Jordan

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A B S T R A C T

Due to chronic water shortage, the Yarmouk basin (north of Jordan) has become an important water resource for both drinking water and irrigation. Despite the increasing dependence on the water of Yarmouk basin, the quality of this water remains questionable. Globally, nitrate is among the most common groundwater contaminants. Studies have revealed that the phreatic groundwater in the northern Yarmouk basin is contaminated by nitrate to a high and variable degree. It has been found that average nitrate concentration is about 46 mg/L. More than 76% of the sampled sites had nitrate concentrations in excess of the human affected (threshold) value of (20 mg/L). This study aims to evaluate nitrate concentration in Yarmouk river basin upper aquifer and predict potential of this ion and to find weather these concentrations agree with the safe range or not. Main data was collected from the Ministry of Water and Irrigation (MWI). Chemical properties of water wells were analyzed and compared to the Jordanian standards. The spatial and temporal changes were studied and nitrate as a pollution indicator was taken into consideration. Pollution and groundwater level maps were generated using a Geostatistical program GS^+ version 5.1, with the Kriging interpolation method. Model runs show obvious that concentration values of nitrate (as a pollution indicator), had increased drastically starting from year 2007, which indicates that the pollution has increased at that period, which could be attributed either to increase of water abstraction or to increased agricultural activities or both.

Introduction

Jordan is an arid to semi-arid country with a land area of 89,206 km^2 that has suffered deficits in water resources since the 1960s. It ranks as one of the world's four most water-stressed countries. Moreover, Jordan is facing the problem of water resources contamination with different types of pollutants, (MWI,2012).

Groundwater accounts for a significant portion of water supply in Jordan. In 2007, water consumption was 940 million cubic meters, of which 54% is groundwater. The increasing rates of groundwater withdrawal due to rising demand from urban residents, industries and agriculture have dramatically dropped the water table more than 2 m within 1 year in some parts of central and northern Jordan. Al-Taani *et al.* (2012), and (Awawdeh and Jaradat, 2009). Jordan's primary sources of water are aquifers and basins fed and recharged through annual rainfall. The groundwater resources of Jordan are subdivided into groundwater basins on the bases of natural boundaries (such as structural features, aquifer extent, and groundwater divides) and administrative boundaries (Ta'any *et al.,* 2007).

Groundwater is a major source of supply for domestic and agricultural purposes, especially in arid and semiarid regions (Nayak *et al.,* 2006; Kumar and Remadevi, 2006; Ahmadi and Sedghamiz, 2007). Crop production in semiarid regions consumes large quantities of water. Accordingly, irrigated crop production exerts a heavy toll on the available scarce groundwater. The demand of water for domestic and industrial use is also increasing (Ta'any *et al.,* 2007).

Yarmouk River Basin is a transboundary basin shared between Jordan and Syria. Only 1,426 km^2 of the basin total area (7,242 km^2), lie within the borders of Jordan. The study area is characterized by altitudes varying from more than 1,150 m in the south to about 200 m below sea level in the northwest. The climate is semi-arid with annual rainfall ranging from about 133 mm in the east to about 486 mm in the west.

The study area is intensively cultivated, and industrial development is expected to increase rapidly in the future (Batayneh, 2010). Due to chronic water shortage, the Yarmouk basin (north of Jordan) has become an important water resource for both drinking water and irrigation. Despite the increasing dependence on the water of Yarmouk basin, the quality of this water remains questionable (Abu-Jaber and Kharabsheh, 2008). The total groundwater withdrawal from Yarmouk Basin was about 50.8 million cubic meters (Margane *et al.,*1999), of which 1.1 million cubic meters was pumped from the B4/**5** aquifer(upper aquifer). The basin is under intensive agricultural production (irrigated and rainfed cultivation) and irrigation with little industrial development (Al-Taani *et al.,* 2012).

Groundwater quality has been deteriorating in many parts of Jordan in recent years due to rapid development, expansion of agriculture, and industrialization. The country, however cannot afford a situation in which precious water resources are lost due to pollution from a wide variety of point and non-point sources including agricultural, domestic, and industrial, (Awawdeh and Jaradat, 2009). Groundwater with nitrate concentration exceeding the threshold of 20 mg/L as NO_3 is considered contaminated due to human activities. Nitrate values between 7 mg/l and 200 mg/l have been recorded in the B4/B5 aquifer in north western Jordan. Though most of the samples are within the desirable limit for drinking water (in Jordan :< 40 mg/l), the elevated nitrate contents clearly indicate that there is a widespread contamination of this aquifer. Many water springs in this aquifer cannot be used for public water supply anymore because of the chemical or bacteriological contamination. (Margane *et al.,* 1999).

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Chronic exposure to high nitrate concentration in drinking water has been linked to adverse health effects on humans, such as colon and rectum cancers, methemoglobinemia in infants, and non-Hodgkin's lymphoma (Ward *et al.,* 1996; Knobeloch *et al.*, 2000; De Roos *et al.*, 2003). Yarmouk basin is the main supplier of domestic and irrigation water for Irbid, northern Jordan Valley and Amman. Therefore, the basin is of special interest and the purposes of this study to evaluate the available surface water potential using the hydrologic characteristics of Yarmouk Basin. And also to prediction of water quality (Nitrate concentration) in upper aquifer (Rijam- B4) by using SWMS_3D model. Finally, give some recommendations for the decision makers and users for the water quality management options.

Materials and Methods

Yarmouk River flows at the borders of Syria and Jordan and joins the Jordan River and Seventy-five percent of this basin lies in Syria. The Jordan, the basin is located between coordinates 210 to 270 E and 210 to 240 N (according to Palestine Grids), covering an area of about 1,426 km^2 (Figure 1).

The adjacent mountain areas and heights (Ajlun Mountains and Golan Heights), which stand at 1,200 m above sea level, are the highest uplands to the east of the Jordan Rift Valley. Yarmouk River flows at the borders between Syria and Jordan, which delineates the Northern boundary of the study area, whereas the Jordan River represents the western boundary (Figure 1). The Yarmouk River originates from Jebal Al-Arab (Syria) and drains from the Jordanian and Syrian territories. The major dam (Al-Wehda Dam) is constructed between Jordan and Syria was constructed across this river. It is proposed that this dam will supply Jordan with about, 110 MCM/yr of potable water. Water quality of the springs, which discharge into the dam, is of great importance for determining the usability of the stored waters (MWI, 2012).

Yarmouk River Basin is highly recharged by rainfall and having good water quality. It is also the main supplier of domestic and irrigation water for Irbid, northern Jordan Valley and Amman. The ground water quality of the Yarmouk basin reflects the land uses within and beyond the basin area, the former is still restricted to rainfed and some irrigated agriculture.

Pollution parameters can be measured in the ground water as well as assessing and simulating its quantity. Nevertheless, simulation of long-term effects of pollution of groundwater of the aquifer has received less attention.

Data collection

The collection of data involves a review of relevant literature to develop a geological database consisting of geomorphologic, geological, geophysical, and soil data. It also includes gathering of detailed information on the previous studies and data from wells drilled for various water, mineral exploration targets, and pollution concentrations in wells water. Data collection will also include the base maps, satellite images, aerial photographs, and geological maps, (MWI, Open Files). The hydrological data includes well location, well depth, well status, aquifer code, water level, test date, well yield, pumping duration, static water level, groundwater salinity, drilling initiation and aquifers properties.

Data Analysis

Chemical properties of water wells were analyzed at the laboratories of Al Balqa' Applied University and compared to the Jordanian standards. The spatial and temporal changes were studied and nitrate as a pollution indicator was taken into consideration. Pollution and groundwater level maps were generated using a Geostatistical program GS^+ version 5.1, with the Kriging interpolation method.

Modeling

Model description

The model solves numerically the Richard's Equation for saturated-unsaturated water flow and the convective dispersive equation for solute transport. The flow equation incorporates a sink term for plant uptake. The program may be used for solute and water transport for unsaturated-saturated, and variable saturated porous media.

The input data for SWMS-3D are given in three input files, while the output results are given by seventeen output files. The model takes into accounts several boundary conditions. These boundary conditions includes specified head (Dirichilet type) boundary conditions, specified flux (Neuman type) boundary conditions , and specified gradients conditions in case of unit vertical hydraulic gradient, simulating free drainage from a relatively deep soil profile. This model can also implement atmospheric boundary conditions. It also can implement seepage face and tile drains. The same system of boundary and initial conditions can be used for solute transport boundary.

Model Parameters and Runs

The needed model parameters were estimated from the literature, which includes soil, weather, chemicals (pollutants), and simulation parameters. The model will be run for (NO_3^-) for different conditions. These conditions include surface and vertical flow. Nitrate was taken as a pollution indicator. One major run for the model was performed for nitrate for 1, 5, 10, 15, 20, and 25 years.

The initial conditions were estimated from the year 2005, to be able to check if the model will be able to predict the concentrations of nitrate in the groundwater wells of the Yarmouk area with sound precision after the first five years. The actual and simulated concentrations of nitrate in wells in year 2010 are presented in Table 1.

Results and Discussion

The following two Figures 2A and 2B obtained from SWMS_3D simulating model illustrate the obvious similarity between the actual and simulated concentrations of nitrate in year 2010 was obtained from SWMS_3D simulating model as illustrated in Figure 2 (A and B).

The similarity between the actual and simulated concentrations validates the SWMS_3D model, which means that the model has been able to predict with fair accuracy the actual values of concentrations and water content of the Yarmouk upper aquifer. That will verify the other results of future values for years 2020**(A)**, 2030**(B);** the effect of river on nitrate concentration was pronounced well in Figure 3 (A and B) due to addition of fertilizers in 2020.

However, a common phenomenon can be observed from Figure 3; it is the increase of nitrate concentration for all years, in particular in 2025–2035, which could be attributed, to severe abstraction of water either from aquifer or to rapid increase in agricultural activities during this period. Figure 4 illustrates locations of the wells used in the model as well as springs in the Yarmouk River Basin upper aquifer.

Figures 5, 6 and 7 show that nitrate concentrations are increasing rapidly for the observation period (2004–2012) which agrees with the results of nitrate concentrations obtained by SWMS_3D model for the simulation period (2006–2030). In addition, it is obvious that concentration values of nitrate (as a pollution indicator), had increased drastically starting from year 2007, which indicates that the pollution has increased at that period, which could be attributed either to increase of water abstraction or to increased agricultural activities, or both.

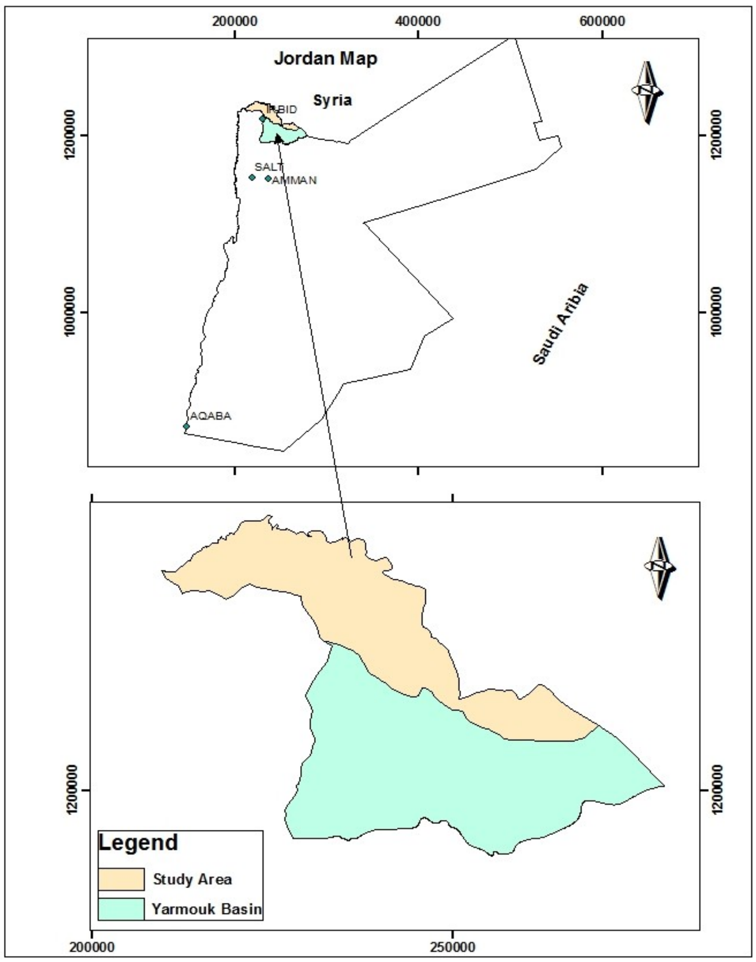
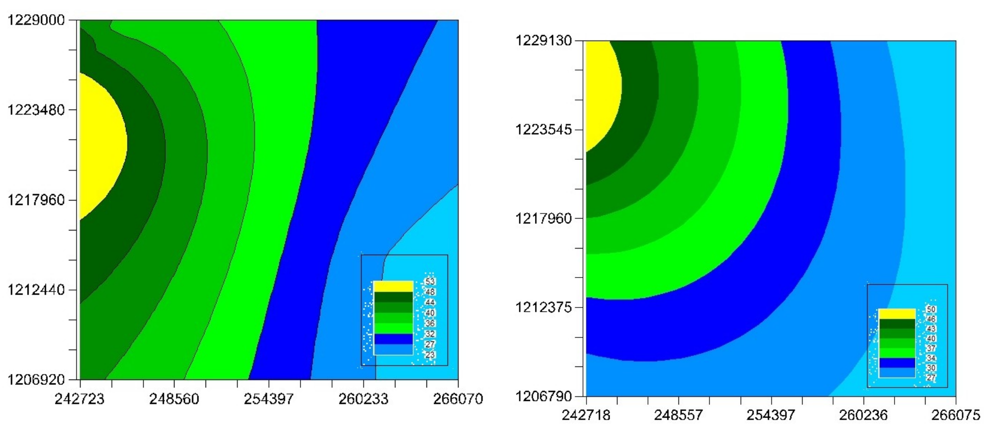


Figure.1 Location map of the Yarmouk basin description

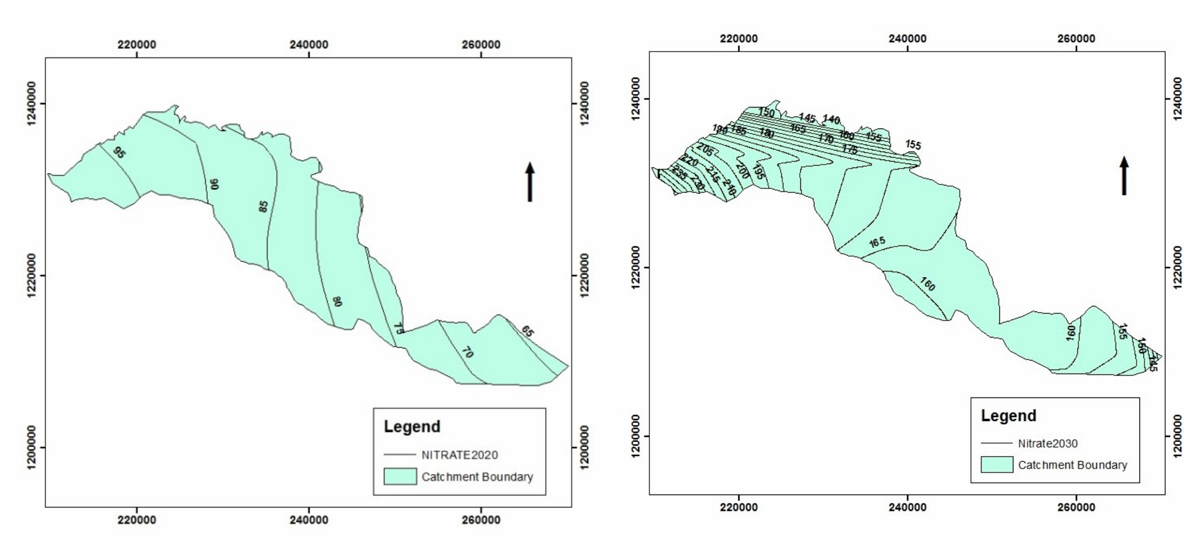
Table.1 Yarmouk actual and simulated nitrate for the year 2010 in (mg/L)

Well code	simulated NO_3^-	actual NO_3^-
AD1037	24.9	26
AD1172	44.7	39
AD1173	44.7	39
AD1251	53	48.9
AD1262	27.4	24.4
AD1281	37.6	40.9
AD1295	41.8	48.4
AD1296	41.8	48.4
AD3004	25.9	26.8
AD3008	44.9	38.4
AD1239	35.8	51.8



(A) **(B)**

Figure.2 (A) Actual nitrate concentration (mg/l) in Yarmouk upper aquifer (2010) and **(B)** simulated nitrate concentration (mg/l) in Yarmouk upper aquifer (2010).



(A) **(B)**

Figure.3 Two maps showing prediction of nitrate concentration in 2020**(A)** and 2030**(B)**

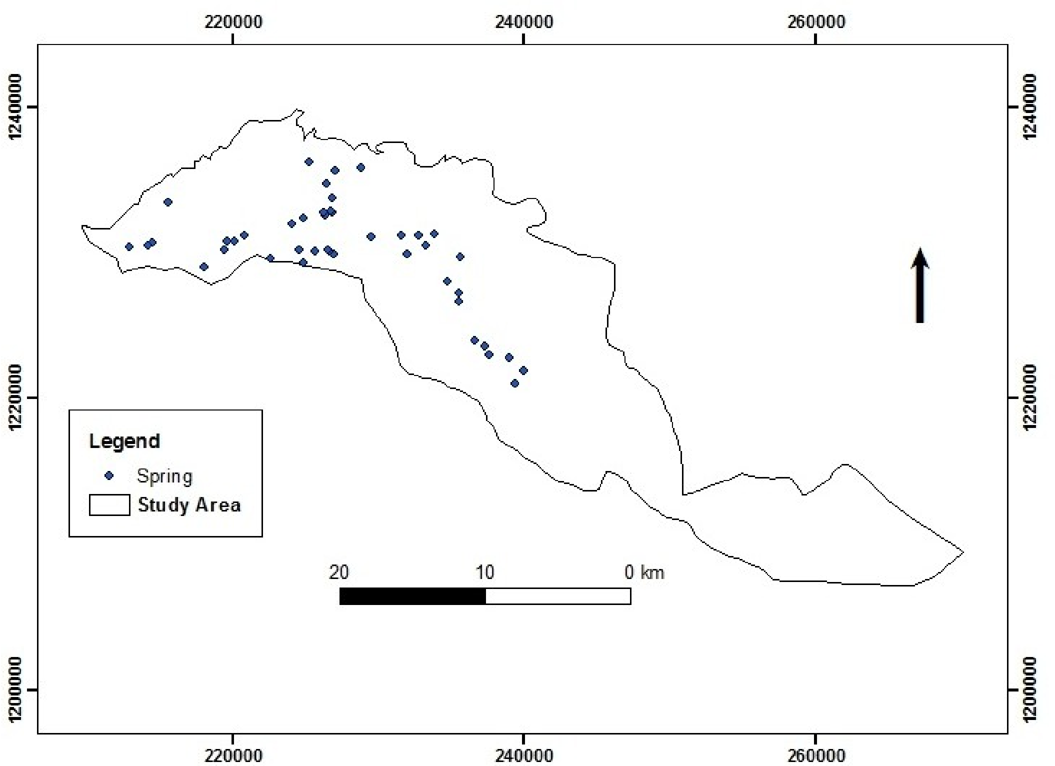


Figure.4 Locations of wells and springs used in simulation of nitrate concentrations in upper aquifer of Yarmouk Basin (triangles represent wells)

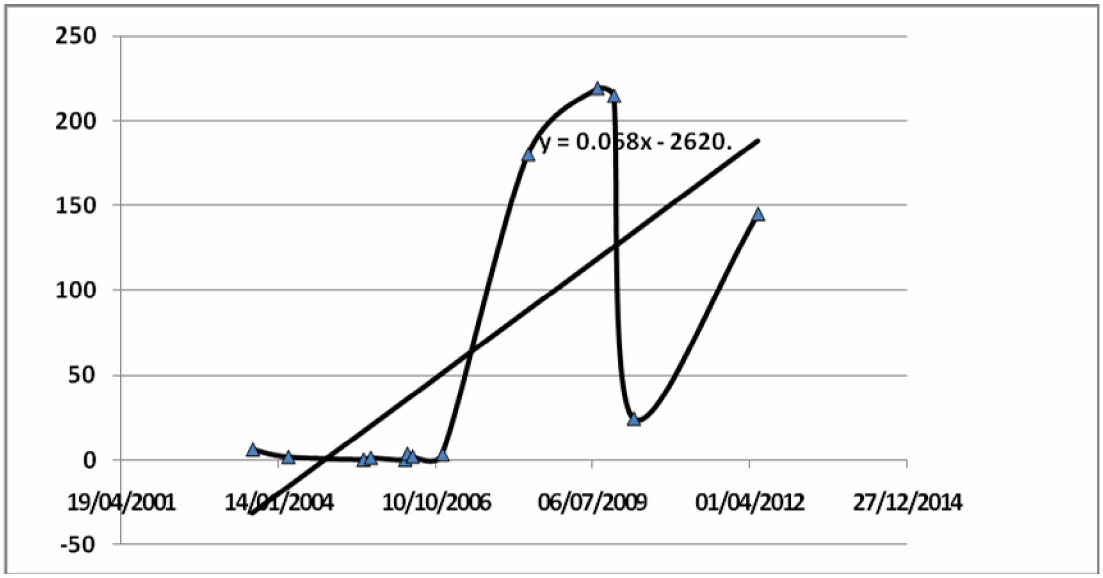


Figure.5 Temporal variation of nitrate concentration (mg/l) in well AD 1295 for the period, (2004–2012)

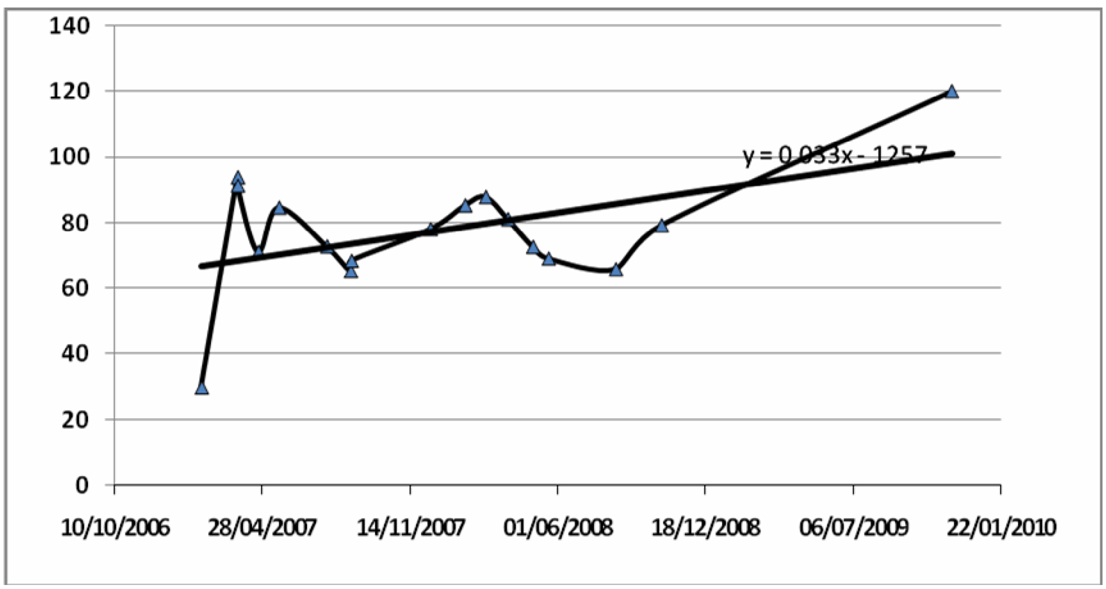


Figure.6 Temporal variation of nitrate concentration (mg/l) in well AD 1251 for the period, (2007–2009)

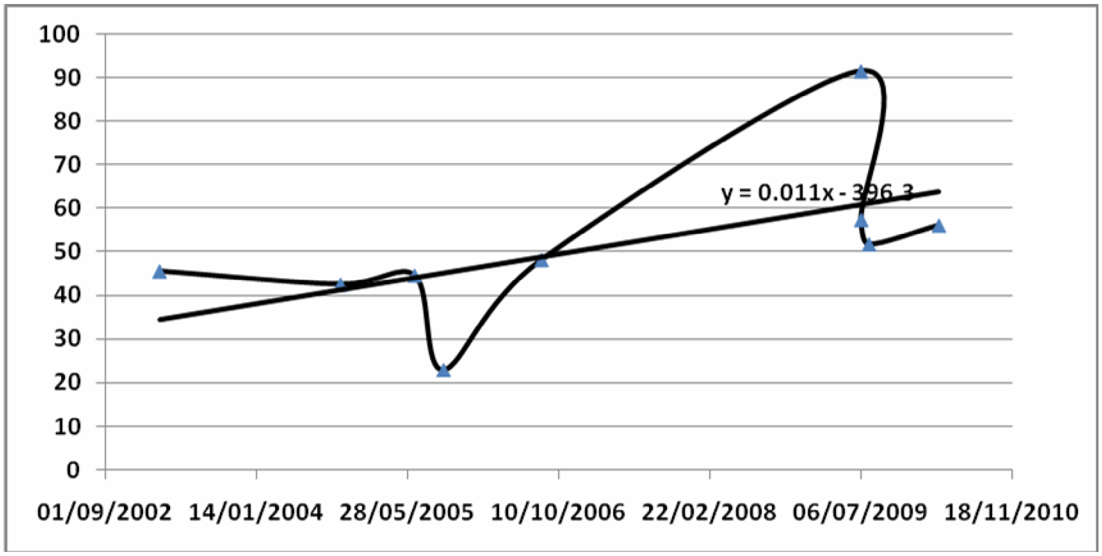


Figure.7 Temporal variation of nitrate concentration (mg/l) in well AD 3011 for the period, (2003–2010)

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