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**Original Research Article**

# Advective Particle Transport Modelling of Potential Contaminated Source Sites in the Lower Pra Basin of Ghana

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**ABSTRACT**

*This research sought to simulate advective particle travel and to estimate contaminant travel path and time in the lower Pra basin. The Groundwater Modeling System (GMS) Version 10.2 was used to develop a numerical model. Potential mining sites were identified and plotted on the model in order to simulate to particle travel time, path and velocity. The advective particle modeling was further done using the PMPATH package in GMS. The advective particle modeling was further done using the PMPATH package in GMS. Two major mining sites which are the Dunkwa and Wassa sites were plotted alongside seven abstraction wells. Wassa mining site was found to be the distant site from the groundwater outlet with an average of 9.1 km length and an average of 102 years with 0.24 m/days. The Dunkwa mining site had an average distance of about 4.8 km from the groundwater discharge point with an average travel time of 84.56 years and travel speed 0.16 m/days. In simulating the various wells with their contaminant abstraction rates, well 2 was found to be the safest well with a travel distance of 17.89 km and travel duration of 247.27 years at a travel speed of 0.20 m/days from possible contaminant site while well 4 has a travel distance of 6.04 km in 72.68-year km travel duration, at a speed of 0.23 m/day. It was found that possible groundwater pollution in the lower Pra basin in Ghana will have little or no immediate impact on downstream groundwater abstractions by residence for their daily groundwater demand.*



## 1. INTRODUCTION

There is no doubt that both small and large-scale mining activities in Ghana have a significant impact on the socio-economic lives of communities and the country at large (Kwesi and Kwasi, 2011). Since the regularization of small-scale mining activities in 1989, there have been tremendous increase in the economic impact by the sector in the country (Kwesi and Kwasi, 2011). This impact may be in the form of job creation especially in regions with no alternative jobs and substantial number of indirect jobs to other sectors of the economy. However, due to the nature of mining, this economic viability has been at a cost to the environment.

With the use of free alluvial ores and gravity concentration by sluicing, mined materials are mixed with mercury in the sluice box to form gold amalgam and further heated to separate the gold (Aryee et al., 2003). Over the years this has been done at various scale until the gold yield has reduced and then abandoned to another site to search for another gold deposit, therefore rendering the environment to severe pollution level (Aryee et al., 2003). The associated pollution can be seen in three different categories which are lithological, hydrologic, and atmospheric in nature. For the case of lithological pollution which is seen as land degradation especially for sites that were not properly monitored or controlled, a bare landscape is left consisting of unstable pile of waste, abandoned excavations and vast stenches of barren land. The excavated pits are typically left uncovered and become receptacle to water and danger to other animals in the community (Aryee et al., 2003). These pits may be a potential site for groundwater pollution, which may arise from leaching of particles to the groundwater aquifers. Although, groundwater pollution tends to reduce in concentration as it travels in time and along its path, the rate of pollution attenuation depends on the geology, hydrogeological settings, geochemical processes and the nature of pollutant (Aryee et al., 2003). This pollution attenuation process may also be by filtration, sorption, chemical processes, microbiological processes or dilution.

It is imperative that the contaminant travel path and time be studied at regional scale to help decision makers and stakeholders of the resources and activities implement a more environmental friendly policy to safeguard the environment, groundwater and health of individuals and communities downstream of mining activities. This research seeks to simulate advective particle travel and to estimate contaminant travel path and time in the lower Pra basin.

## 2. METHODOLOGY

### 2.1. Description of Study Area

The lower Pra basin has a population of about 1.5 million people, who live and work in various villages, medium sized towns and metropolitan cities. The population growth rate is estimated to be about 2.2 % per annum (WRC, 2012). The lower Pra basin encloses about 9 districts which are divided into: 5 in the central region, 1 in the eastern region and 3 in the western region as shown in Figure 1. Basically, the major economic activities in the basin include agriculture which consists of farming of food crops, fruits and cash crops like cocoa, oil palm, coffee, banana, plantain and vegetables. The rural inhabitants also engage in oil palm extraction, cutting of trees for fuelwood and charcoal production for domestic uses and the use of inorganic fertilizers for agricultural activities. Most towns are prominent for their mining activities. Gold was mined from the channel of the Offin river at Dunkwa. These mining activities have caused danger to the environment especially land degradation and surface water pollution (Aryee *et al.*, 2003). Also, other human induced environmental degradation include tree falling and improper farming practice. The mining activities (small and large-scale mining) have additionally degraded the land and littering portions of the basin with trenches and water crammed excavations that have not been reclaimed. These waters filled excavations generally have turbid waters containing other chemical pollutants from gold excavation and diamond mining.

Table 1 present sites that were selected as potential groundwater contaminant sites to simulate contaminant path in various geological formation in the basin. The choice of selection is based on historical events and the researcher perception to study contaminant travel path and time in various geological formation and the suggested model characteristics like hydraulic conductivities range and distribution.

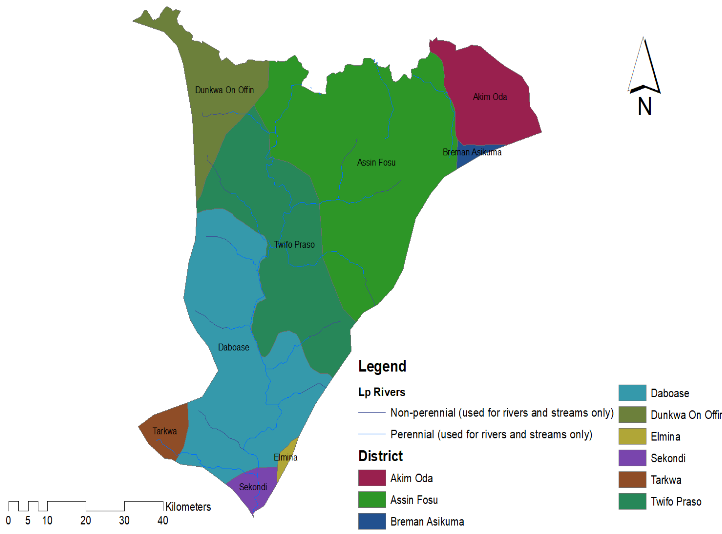


Figure 1: Map of the Lower Pra Basin illustrating hydrological and administrative features

Table 1: Selected particle travel sources sites in the lower Pra basin

| S/N | Flow particles | Community | Region | Aquifer material |
|---|---|---|---|---|
| 1 | Dunkwa mine | Dunkwa | Central | Birimian sediment |
| 2 | Wassa mine | Wassa | Western | Birimian sediment |
| 3 | Well 1 | Ankanb | Central | Schists |
| 4 | Well 2 | Agona Tema | Central | Granite-schist contact |
| 5 | Well 3 | Obrayeko | Central | Granite / Gneiss |
| 6 | Well 4 | Antwi Kwaa | Central | Granite / Gneiss |
| 7 | Well 5 | Kwame Alex | Central | Granite-schist contact |
| 8 | Well 6 | Brentuokrom | Central | Sandstones |
| 9 | Well 7 | Abrawdiwured | Western | Dahomeyan Rocks |
| 10 | Kankuase | Kankuase | Central | Dahomeyan Rocks |

## 2.2. Modelling Approach

The Model development was done by first developing a conceptual model for the study area and the converting this conceptual model into numeric model. Model conceptualization was done using the ArcGIS software to process the model data into acceptable format and then imported using the map tool in the Groundwater Modeling System (GMS) versing 10.3. The hydraulic conductivity and the recharge properties of the model domain was used to create zones within the model domain. No flow boundary conditions were assigned to the domain sides while the specific head boundary was assigned to the northern part of the domain. The specific boundary head was used to define the rivers as the upper boundaries of the model. While the bottom if the model was assigned a no flow boundary. The model thickness was defined based on the depth of the boreholes data. Sources and sinks in the model were defined based on wells, river and specific head boundary. The model recharge and hydraulic conductivities were assigned using the hydraulic conductivity package of the model. The model top and bottom were obtained by subtracting the static water level and borehole depth from the Digital Elevation Model (DEM) of the area respectively. After developing the conceptual model, it was then converted into a numerical model to simulate groundwater flow in the basin. The numerical simulation was done with the MODFLOW (Harbaugh, 2005), incorporated in the Groundwater Modeling System (GMS). The model calibration for the study area was achieved by comparing the computed head with the measured head at a minimum head difference. This calibrated groundwater flow model was used to simulate particle tracking using the PMPATH package of GMS. The PMPATH is an advective transport model running independently on the GMS software. It uses a semi-analytical particle tracking scheme to calculate the groundwater travel path and time, and produces results in various format such as contours, drawdown heads and velocity vectors for a selected model and time. As such, PMPHT can be used to simulate advective transport in groundwater and to delineate capture zones and protection zones. It creates output file including hydraulic distribution, velocity field and travel time of particles.

The numerical model was developed by getting a thorough understanding of the basin aquifer system which include their geology, hydrogeology and spatial distribution of aquifer materials. This was achieved through detail review of previous works and literatures relating to the study (Yaouti *et al*., 2008; Hu *et al*., 2011; Mark *et al*., 2011; Gusyev *et al*., 2014). Complementary data set were obtained from Community Water and Sanitation Agency (CWSA), Ghana. These data sets include borehole drilling data which comprises of borehole location and ID, specific yield, depth of borehole, static water level and aquifer materials. The static water level was subtracted from the borehole elevation and was used for calibrating the model since the borehole were drilled during low groundwater abstraction. As such it was assumed that the groundwater fluctuations are relatively same for the period.

A sensitivity analysis was performed on the model parameters to determine the ones with optimum impact on the model output on adjustment of its values. The hydraulic conductivity and groundwater recharge were found to be the most sensitive parameters and were adjusted with the pilot point automatic PEST calibration support to obtain optimum model performance.

### 2.3. Simulating Particle Travel Path and Time

In order to study the contaminant travel path and time in the basin, it was assumed that the porosity of the aquifer varies according to the borehole yield distribution and the geological formation intercepted by the boreholes. The assumption is based on the continuum approach for characterizing fracture-controlled aquifers. As such it was assumed that the aquifers are of equivalent porosity and the estimated hydraulic conductivities were valid for this study. Particle tracking simulation was conducted on seven boreholes with abstraction rate ranging from 0.6 L/s to 181 L/s. Two potential contaminant sources were simulated to study the particle travel path and time to sink in the model. The abstraction rates for boreholes closer to the pollution sources were increased by 20 %, 50 % and 100 % to observe the contaminant capture zones by the wells and corresponding flow rate.

## 3. RESULTS AND DISCUSSION

Figure 2 illustrates the particle tracking simulation for the two mining sites and seven abstraction wells in the basin. The travel time from these sites to their respective discharge areas and the travel paths as well as travel time and path for the abstraction wells are shown in Table 2. It was observed that the Pra river is the discharge point for the mining areas while the abstraction wells are supplied from a higher head point. The nearest flow path to the Pra River recorded is the Dunkwa mine with about 4851.93m from the discharge point, while the Wassa mine is about 9702 m from the river. The particle flow velocity ranged from 0.02 m/day to 0.23 m/day. The estimated particle travel time from the mine sites to the Pra river is about 84.56 years for the Dunkwa mine and 102.62 years for Wassa mine as shown in Figure 3. The travel time defines the advective particle movement along the identified flow path in the model domain. It is observed from Table 2 that particles from the Dunkwa mine, Wassa mine and Kenkuas community get leached into the subsurface by rainfall and are transported by groundwater flow velocity to nearby streams as discharge. Though the rate of contaminant transport is slow leaving pollutants in the groundwater system for a long time as seen from the particle travel time, the quality of groundwater is placed at risk for residence of communities sharing groundwater source boundaries with mining companies on the upstream. This is severe when contaminant particles travel along the stream path to discharge at a lower point as in the case of the Wassa mine. It is seen that particles from the Dunkwa mine take about 84 years to travel to the point of discharge with a flow velocity of about 0.16 m/day and as such groundwater aquifer will store contaminant for about this period for a particular advective particle contamination event. The Wassa mine possess a more severe contamination situation for its aquifers since particles can travel for 102 years at a flow velocity of about 0.24 m/day.

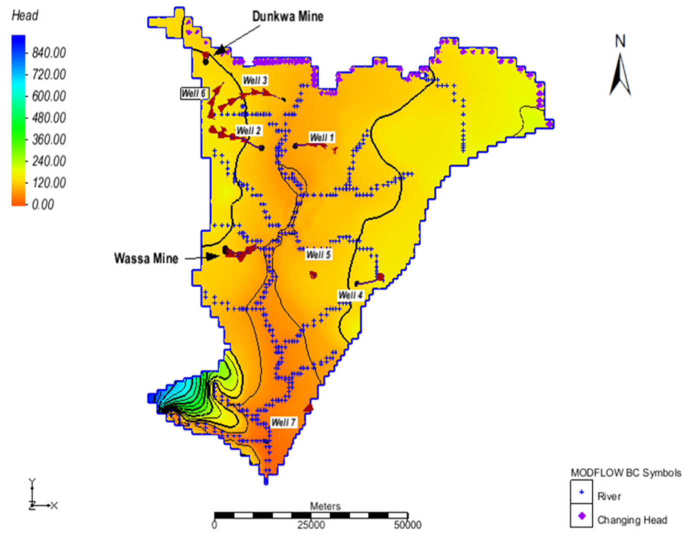


Figure 2: Map showing particle travel path from the selected source areas

Table 2: Particle tracking parameters for the selected sites in the lower Pra basin

| S/N | Flow particles | Length (m) | Travel time (years) | Average velocity (m/days) |
|---|---|---|---|---|
| 1 | Dunkwa mine | 4851.93 | 84.56 | 0.16 |
| 2 | Wassa mine | 9117.86 | 102.62 | 0.24 |
| 3 | Kankuase town | 5719.41 | 110.93 | 0.14 |
| 4 | Well 1 | 9471.55 | 502.32 | 0.05 |
| 5 | Well 2 | 17895.63 | 247.27 | 0.20 |
| 6 | Well 3 | 17454.63 | 225.01 | 0.21 |
| 7 | Well 4 | 6044.55 | 72.68 | 0.23 |
| 8 | Well 5 | 8156.46 | 997.52 | 0.02 |
| 9 | Well 6 | 9910.43 | 146.00 | 0.19 |

Simulation of the boreholes to observe the abstraction path for the boreholes and time of travel of flow to point of abstraction was carried out on seven boreholes and are shown in Table 3. The backward flow simulation was conducted for the wells to estimate the flow path and travel time of groundwater towards the boreholes. Well 4 which is in the Antwi Kwaa community shows the shortest flow path for groundwater of about 6044.55 m with a flow velocity of 0.23 m/day. Its contamination time will take about 72.68 years for particle to travel from a point of high groundwater head to its location. Well 2 which is in Agona Tema community has the farthest point of abstraction of groundwater with an abstraction flow velocity of about 0.20 m/day and a time lag of about 247 years to be contaminated by potential pollute sites upstream of its location. Well 1 which is in the Ankanb community will take about 502 years to be contaminated though its travel length is about 9471.55 m. flow velocity is about 0.05 m/day. This is as a result of the distribution of groundwater head in the region of the borehole which are function of hydraulic conductivity and groundwater recharge. A similar situation is seen for well 7 which is Abrawdiwured community. Well 7 has a flow path length of about 12622.99 m with a flow velocity of about 0.08 m/day and particle travel time of about 442.16 years to the well. The groundwater head within well 1 Is about 67 m while its hydraulic conductivity and recharge are 4.91 m/day and 0.05 mm/day respectively. Groundwater head for well 7 is about 44.91 m while its corresponding hydraulic conductivity and recharge are 10.17 m/day and 0.103 mm/day respectively. It can be inferred that groundwater flow velocity is a factor of the hydraulic conductivity in the region which is the ability of groundwater materials transmit water and the rate at which water will flow under a given hydraulic gradient.

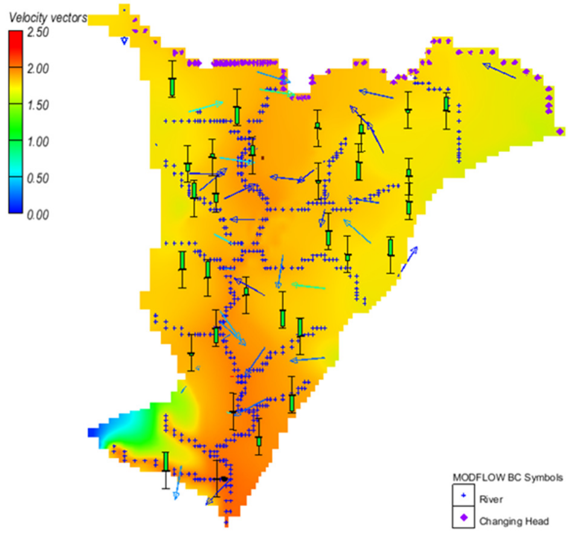


Figure 3: Particle velocity field map

Table 3: Particle tracking parameters for the abstraction wells in the lower Pra basin

| S/N | Flow particles | Length (m) | Travel time (years) | Average velocity (m/days) |
|---|---|---|---|---|
| 1 | Well 1 | 9471.55 | 502.32 | 0.05 |
| 2 | Well 2 | 17895.63 | 247.27 | 0.20 |
| 3 | Well 3 | 17454.63 | 225.01 | 0.21 |
| 4 | Well 4 | 6044.55 | 72.68 | 0.23 |
| 5 | Well 5 | 8156.46 | 997.52 | 0.02 |
| 6 | Well 6 | 9910.43 | 146.00 | 0.19 |
| 7 | Well 7 | 12622.99 | 442.16 | 0.08 |

## 4. CONCLUSION

The study has clearly showed that there is the need to ascertain the level of impact of mining on groundwater across mining regions in the country; this is to ensure that the groundwater condition is perfect and prevention of water poisoning and epidemics. The model results obtained revealed that the mining sites contribute less to the pollution of groundwater within the study catchment. This information is useful to the government and other water agencies for planning and pollution abatement.

## 5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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