International Journal of Scientific Research and Engineering Development-– Volume 7 Issue 3, May-June 2024
Available at www.ijsred.com

RESEARCH ARTICLE OPEN ACCESS

Assessing the Impact of Solid Waste Disposal to Groundwater Quality in San Rafael, Guagua, Pampanga Using MODFLOW and MT3DMS

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Abstract:
Management of solid waste has been a major problem over the past years due to the rapidly growing population which eventually led to the increased amount of garbage thrown. In this study, a dumpsite located in Barangay San Rafael, Guagua, Pampanga was assessed due to the potential risks it may pose to groundwater resources and human health. The groundwater flow in the study area and the transport of contaminants were modeled using advanced groundwater modeling MODFLOW software and MT3DMS modeling. A Graphical User Interface (GUI) such as the ModelMuse, was used to execute the codes of the mentioned software. The contaminants Arsenic (As), Copper (Cu), and Chromium (Cr) were selected due to the possible risk they may pose to human health and the environment. The mentioned contaminants were simulated to determine their travel distance for 1, 2, 5, 15, 25, 40, and in 50 years. The generated results from the study indicated that the parameters As, Cu, and Cr have concentration values of 0.0105 mg/L, 0.909 mg/L, and 0.369 mg/L respectively, thus, these three contaminants may be the primary cause of groundwater pollution in the future. The flow of groundwater is toward the middle portion of the study area, and it is evident that as time increases, the affected area of the contaminant also increases. The groundwater in areas that were located near the dumpsite and along the groundwater flow was more susceptible to pollution and contamination risks. Furthermore, for the calibration of models using TDS, the projected error for Location 1 (40m from the dumpsite) and Location 2 (100m from the dumpsite) were 0.696 and 0.570 percent respectively, thus, these models can be utilized in monitoring groundwater conditions.

Keywords **— Dumpsite, Groundwater Flow, ModelMuse, MODFLOW, MT3DMS, Transport of Contaminants**

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I. INTRODUCTION

Solid waste has been a major problem over the past years. The rapidly growing population and the increasing demands of every individual escalated the amount of waste that was being thrown by every household on a daily basis. Due to this, the pressing issue regarding proper disposal, segregation, and recycling of waste has become imperative. In order to address this problem, the Philippines amended the Republic Act 9003, also known as the "Ecological Solid Waste Management Act of 2000". The aim of R.A. 9003 was to protect the people and the environment by providing a detailed and standardized plan and program with regard to waste management [1]. Despite extensive studies, regulations, and policies over the years, solid waste management continued to be a significant challenge for the nation, particularly in highly urbanized areas.

Areas with large populations struggle with the management and efficient solid waste disposal. The facilities intended for proper management of solid waste are insufficient to accommodate every garbage thrown, leading to improper and unmanaged disposal practices. This issue doesn't lead only to environmental-related problems but also poses risks to the health of the residents living in areas exposed to hazards and contaminants from different garbage.

The wastes, which are heterogeneous, are eventually thrown in landfills and dumpsites. This can cause discomfort and health risks to those people who are residing near the open dumpsite because of the unpleasant odor from the tons of waste. Additionally, the properties and characteristics of the land as well as the groundwater may change due to the contaminants and impurities from the dumpsite. These may lead to serious environmental and health damages since groundwater plays a crucial role in sustaining the water needs of people for domestic, agricultural, and industrial uses.

Groundwater is highly vulnerable to pollution and contamination because of the different significant factors that may transport contaminants from the dumpsite. In addition, rainfall events contribute to the increased flow of toxicants and contaminants in the groundwater source [2]. Leachate is a hazardous substance that is generated as a consequence of the physical, chemical, and biological changes that occur in municipal solid waste, and It is characterized by its high level of toxicity [3]. This liquid can be hazardous to the environment and may be dangerous to public health once it seeps through the groundwater, thus, it must be managed carefully to minimize its influence on the environment. Leachate percolation causes environmental degradation because of the improper and indiscriminate disposal of wastes. Thus, the quality of water near waste storage needs to be tested first to know if it is safe for human consumption before using it for drinking purposes.

In the Municipality of Guagua, Pampanga, all 31 barangays dispose the Municipal Solid Waste (MSW) in a dumpsite located at Barangay San Rafael, Guagua. The said dumpsite doesn't have a liner system, making it susceptible to leachate percolation. Once the wastes from the dumpsite percolate and seep through the ground, contamination and water pollution will be a serious problem for the community because groundwater is a source that is being utilized by the residents in Guagua, Pampanga for various purposes. Hence, continuous studies and a dire need for solid waste management improvement are critical since most people are dependent on groundwater sources.

Open dumpsites, which don't usually have any liner system as barricades and barriers at the bottom, often lead to contamination and pollution. The researchers wanted to assess the impact of solid waste disposal on the quality of groundwater thoroughly, by exploring the possible sources and the type of contaminants present.

The delicate balance between consumption and environmental responsibility underlies the management of MSW, the environmental health outcome emphasized. SWM was a major societal challenge, requiring considerations of economic, environmental, legal, political, resource, and socio-cultural, and logistical issues related to material disproportionate disposal was a major challenge for Asian countries. Groundwater plays a crucial role in meeting people's water demand, however, improper management and pollution pose challenges. The Philippines, which has a vast groundwater reservoir, faces water quality threats due to the rapid population growth and industrialization.

Groundwater contamination due to human activities was characterized by undesirable inputs. Runoff from landfills contributes to groundwater contamination, carrying contaminants from waste breakdown. Proximity to landfills increased the risk of contamination, posing risks to local users and the environment. The impact of land disposal on groundwater and surface water is of great concern, especially in light of population growth. Contaminant transfer was a concern during waste disposal, where contaminants move through porous soil.

The study used models such as Visual MODFLOW to simulate flow groundwater and MT3DMS for the movement and transport of contaminants. The model helped in predicting the direction and rate of groundwater movement and flow, and balances production with hydrological conditions. MODFLOW and MT3DMS software illustrated the importance of understanding and monitoring groundwater contamination.

This study aims to determine the scope and qualities of groundwater contamination caused by current solid waste disposal practices and to recommend effective measures for protecting and improving groundwater quality. Specifically, the goals of this study are the following:To test the leachate sample in the dumpsite, and two water samples from two locations approximately 40 meters and 100 meters from the dumpsite to know if there are traces of contaminants; to model the flow of groundwater in San Rafael, Guagua, Pampanga with the use of MODFLOW; to determine and generate pathways of potential contaminants through the application of MT3DMS; and to propose recommendation and remediation strategies for enhancing solid waste disposal practices with potential implications on the groundwater quality in the locality of San Rafael, Guagua, Pampanga.

II. METHODOLOGY

A. Research Design

This study adopted a Case Study approach to investigate the impact of solid waste disposal on groundwater quality and to examine groundwater contaminant transport in Guagua, Pampanga. The aim was to investigate this real-life problem using MODFLOW and MT3DMS modeling methods and simulation in order to predict groundwater flow and contaminant transport. Specifically dealing with San Rafael Guagua, the research focused at how dumpsites had contributed to groundwater pollution. This study investigated the dynamics of groundwater flow as well as transportation of contaminants which are responsible for the environmental challenges that are specific to this community. The case study design availed a comprehensive grasp on how hydrogeologic factors affect contaminant migration within the aquifer. Simultaneously, the collection of leachate and water samples from the dumpsite as well as deep wells around disposal sites to assess characteristics of groundwater quality was employed. The goal behind analyzing results from the modeling data was to establish a sound understanding of how solid waste dumping affects groundwater quality in San Rafael, Guagua Pampanga.

B. Research Locale

The study took place in San Rafael, Guagua, Pampanga where the dumpsite is located. Barangay San Rafael has been heavily reliant on groundwater and the dumpsite is likely to cause pollution of groundwater because it is where all the wastes collected in the whole municipality of Guagua were dumped. Moreover, the pollution of groundwater poses a great risk to people's lives and it may present a threat to maintaining the well-being of the community.

C. Research Instrument

A Case Study approach was employed simultaneously through the use of MODFLOW and MT3DMS software, field surveys, laboratory analyses, and groundwater modeling and mapping. These software packages were the main tools in generating a simulation of the groundwater flow and the contaminant transport in Guagua aquifer system. Aquifer properties and boundary conditions, pumping rates, contaminant sources, and others were input to the software-generated model and were varied to simulate different scenarios so that the effects of scenarios on groundwater quality could be assessed. The microbial characteristics of groundwater samples collected from adjacent deep wells were analyzed in a laboratory for identification of bacterial pathogens and types of contaminants in water resources. Moreover, maps of contamination hotspots and likely travel paths were generated by the simultaneous use of MODFLOW and MT3DMS tools while spatial distribution patterns of pollutants were interpreted from the obtained data. Some information for validating/calibrating those models was obtained from groundwater monitoring wells and some sample points within the studied area.

D. Data Collection

The researchers gathered essential data regarding on the quantity and types of solid waste disposed of at the San Rafael, Guagua, Pampanga dumpsite, as different materials can variably impact the quality of groundwater. Furthermore, they developed a simulation model of groundwater flow and the movement of contaminant from the dumpsite into the groundwater with the use of advance software modeling such as MODFLOW and MT3DMS. To utilize MODFLOW, data such as Geographical Plan, Borehole Data, Cross-sectional Area and Hydraulic Surveys, are needed to in defining the area of the dumpsite. The researchers analyzed the results from the simulation to evaluate the possible impact of pollutants on the quality of groundwater and to find the areas that at the highest risk of contamination.

E. Research Procedure

In order to obtain the intended outcome of the study, systematic steps and procedures were adopted. This involved a strategic combination of data collection, modeling and simulation using MODFLOW and MT3DMS, and statistical analysis of the outputs. Additionally, this phase was broken down into five (5) stages: preliminary sample testing, modeling of groundwater flow, simulation of contaminant transport, actual testing of groundwater, and recommendations.

1) *Stage 1: Preliminary Sample Testing*
   In this stage, the researchers identified what specific contaminant that originates from the dumpsite to be modeled and simulated in MODFLOW and MT3DMS by getting samples from the nearest water tank and deep well. A total of three (3) samples were generated, the researchers obtained leachate sample from the dumpsite, and two (2) water samples from the deep wells located approximately 40 meters and 100 meters from the dumpsite. The samples were subjected to laboratory testing. After getting the results, the contaminants to be modeled were specified.
2) *Stage 2: Modeling of Groundwater Flow using MODFLOW*
   After specifying the contaminant to be modeled, the actual model of the groundwater flow was created using MODFLOW. In order to generate the desired outcomes in the software, the Geographical Plan of the dumpsite located in Barangay San Rafael was a prerequisite. A geographical plan represented the grid formation, which indicated the spatial distribution of the area that was simulated. Other than the geographical plan, Borehole Data was also utilized to know the different layers and properties of soil in the dumpsite. Additionally, data regarding the Cross-sectional Area were crucial as it provided significant information about the elevation of the land, and accurately represents the three-dimensional subsurface structure in the model. Furthermore, a Hydraulic Survey was also an essential requirement as it involved measuring of groundwater level in the area. Upon completing and inputting the needed data, the MODFLOW was used to model the flow of groundwater.
3) *Stage 3: Simulation of Contaminant Transport using MT3DMS*
   Once the particular contaminant to be modeled was determined and the flow of the groundwater was recognized, the next step involved the contaminant transport to be simulated. The generated output from MODFLOW was used as input for the utilization of MT3DMS software, enabling the researcher to locate the path of the contaminant. The simulation for contaminant from MT3DMS produced a visual representation of the movement of contaminant and the pathways within groundwater along with the time needed for contaminants to move between different points in the groundwater.
4) *Stage 4: Actual Testing of Groundwater*
   After the fulfillment of modeling and simulation, the researchers proceed to the next step which is to validate the reliability and accuracy of the results from MODFLOW and MT3DMS by comparing the output from the software to the actual laboratory testing result. This comparison highlighted the evaluation of how well models simulated the behavior of groundwater flow and contaminant concentration as indicated by the laboratory test. This phase was critical for establishing the credibility and adequacy of the software in understanding and tackling groundwater contamination issues.
5) *Stage 5: Proposal of Possible Recommendations*
   After the fulfillment of modeling and simulation, the researchers proceed to the next step which is to validate the reliability and accuracy of the results from MODFLOW and MT3DMS by comparing the output from the software to the actual laboratory testing result. This comparison highlighted the evaluation of how well models simulated the behavior of groundwater flow and contaminant concentration as indicated by the laboratory test. This phase was critical for establishing the credibility and adequacy of the software in understanding and tackling groundwater contamination issues. The limitations that were seen in the process of using the models were determined in this stage. Moreover, possible remedies regarding the managerial aspects of the dumpsite were also recommended.

III. RESULTS AND DISCUSSIONS

A. Heavy Metal Concentrations

The researchers started with the identification and investigation of heavy metal concentrations from the extracted leachate sample from dumpsite at approximately 3m in depth, and the water samples from the two locations, approximately 40 meters from the dumpsite and 100 meters from the dumpsite. The contaminants that were tested in the laboratory were three (3) heavy metals that the researchers selected and were found in the groundwater. Those heavy metals were Arsenic (As), Copper (Cu), and Chromium (Cr). The mentioned parameters were found in the dumpsites as various wastes can generate these contaminants. Discarded electronic devices, pesticides, agricultural wastes, and treated wood contribute to As contamination [4]. Moreover, Cu contaminant, may be from the electrical wires, discarded smartphones and other gadgets, damaged appliances, and batteries [5]. Furthermore, Cr contaminant may be generated from electronic components, cleaning agents used in households, lithium-ion batteries, paints, and thrown steel scraps [6] [7].

The mentioned contaminants were considered hazardous and may have negative and long-term effects if not handled and treated. For instance, drinking water that has high concentration levels of the contaminants As, Cu, and Cr has various negative health implications. For As, it may lead to acute arsenic poisoning which causes abdominal pain, diarrhea, vomiting, muscle cramps, and numbness. In addition, it can also result in cancer in the skin, bladder, and lungs [8]. For Cu, it may result in gastrointestinal symptoms including abdominal pain, diarrhea, nausea, and vomiting. Additionally, it may cause a damaged liver, commonly in infants and children [9]. Furthermore, for the contaminant Cr, drinking water with a high concentration of this contaminant may damage the liver and intestine, and may result in anemia and cancer [10] [11].

Considering the DENR Administrative Order 2016-08 [12], the limits were determined based on beneficial use. The laboratory results were compared to three classifications, those were Class A - Public Water Supply Class II, which served as the guidelines for water supply sources that require conventional treatment in meeting the Philippine National Standards for Drinking Water (PNSDW) standards, Class B, which served as a guideline for recreation involving primary contact like bathing, and Class C, which showed the guidelines for agriculture and irrigation works.

TABLE I
CONCENTRATIONS OF THE HEAVY METAL FROM THE EXTRACTED LEACHATE WITHIN THE DUMPSITE

Parameters	Method	Limit (By Classification)			Result
		A	B	C	
Arsenic (As)	SMEWW 3114 B	**0.01**	**0.01**	**0.02**	**0.0105 (mg/L)**
Copper (Cu)	SMEWW 3120 B	**0.02**	**0.02**	**0.02**	**0.909 (mg/L)**
Chromium (Cr)	SMEWW 3120 B	**0.01**	**0.01**	**0.01**	**0.369 (mg/L)**

Table 1 indicates the results of the heavy metal concentrations in the leachate sample collected within the dumpsite. For the heavy metal parameter Arsenic (As), results revealed that the sample had recorded a 0.0105 mg/L value that is greater than the method detection limit (MDL) of 0.01 mg/L for both Class A and Class B, but less than the MDL of Class C which value is 0.02 mg/L. Subsequently, for the parameter Copper (Cu), results showed that the sample contained 0.909 mg/L, which showed a higher value than the indicated limit of 0.02 mg/L for Class A, B, and C. Moreover, for the parameter Chromium (Cr), the results of the laboratory tests show a value greater than the indicated MDL because the results showed a value of 0.369 mg/L while the indicated limiting value was 0.01 mg/L for Class A, B, and C. In conclusion, the results for Table 1 indicate that there were traces of the three (3) heavy metals in the leachate sample collected within the dumpsite. The parameter As exceeded the limiting value for Class A and B but not for Class C, meaning for agriculture and irrigation, it is still safe to use. Meanwhile, the parameters Cu and Cr exceeded the limiting values for Class A, B, and C, which only means that they are hazardous.

TABLE II
HEAVY METAL CONCENTRATIONS FROM THE EXTRACTED WATER SAMPLE IN LOCATION 1 (40M FROM THE DUMPSITE)

Parameters	Method	Limit (By Classification)			Result
		A	B	C	
Arsenic (As)	SM 3030 F. / SM 3114 B.	**0.01**	**0.01**	**0.02**	**0.015 mg/L**
Copper (Cu)	SM 3030 F. / SM 3111 B.	**0.02**	**0.02**	**0.02**	**0.025 mg/L**
Chromium (Cr)	SM 3030 F. / SM 3111 B.	**0.01**	**0.01**	**0.01**	**0.035 mg/L**

Table 2 shows the results of the concentrations of heavy metal in the water sample collected from a deep well hand pump located 40 meters from the dumpsite. For the heavy metal parameter Arsenic (As), results show that the water sample that was recorded has a value of 0.015 mg/L, which was greater than the MDL of 0.01 mg/L in both Class A and Class B, but less than the MDL value of 0.02 mg/L for Class C. Next, for the parameter Copper (Cu), the laboratory result was greater than the limiting value indicated for Class A, B, and C because the water sample contained 0.025 mg/L, which was greater than the indicated limit of 0.02 mg/L. Moreover, for the parameter Chromium (Cr), the results of the laboratory tests indicated that the parameter was greater than the indicated MDL value because the water sample results showed a value of 0.035 mg/L while the indicated limiting value was 0.01 mg/L for Class A, B, and C. In conclusion, the results for Table 2 indicated that there were traces of the three (3) heavy metals in the groundwater sample collected from a deep well located 40 meters from the dumpsite. The parameter As exceeded the limiting value for Class A and B, but less than the limiting value for Class C, which means it is still safe to use for agriculture and irrigation. The parameters Cu and Cr have exceeded the limiting value, which may pose significant health threats.

TABLE III
HEAVY METAL CONCENTRATIONS FROM THE EXTRACTED WATER SAMPLES IN LOCATION 2 (100 M FROM THE DUMPSITE)

Parameters	Method	Limit (By Classification)			Result
		A	B	C	
Arsenic (As)	SM 3030 F. / SM 3114 B.	**0.01**	**0.01**	**0.02**	**0.0076 mg/L**
Copper (Cu)	SM 3030 F. / SM 3111 B.	**0.02**	**0.02**	**0.02**	**0.025 mg/L**
Chromium (Cr)	SM 3030 F. / SM 3111 B.	**0.01**	**0.01**	**0.01**	**0.035 mg/L**

Table 3 shows the results of the concentrations of heavy metal in the water sample collected from a deep well hand pump located 100 meters from the dumpsite. For the heavy metal parameter Arsenic (As), results revealed that the water sample that was recorded has a value of 0.0076 mg/L, which was less than the MDL of 0.01 mg/L in both Class A and Class B, and 0.02 mg/L for Class C. Next, for the parameter Copper (Cu), results showed that the water sample contained 0.025 mg/L, which was greater than the indicated limit of 0.02 mg/L for Class A, B, and C. Moreover, for the parameter Chromium (Cr), the results of the laboratory tests indicated that the heavy metal parameter is greater than the indicated MDL value because the water sample results showed a value of 0.035 mg/L while the indicated limiting value was 0.01 mg/L for Class A, B, and C. In conclusion, the results for Table 3 indicated that there were traces of the three (3) heavy metals in the groundwater sample collected from a deep well located 100 meters from the dumpsite. The parameter As haven't exceeded the limiting value yet, which means it is not in the alarming zone. On the other hand, the parameters Cu and Cr can be considered hazardous already because they have exceeded the limiting value.

B. Groundwater Table Contour Map of Guagua, Pampanga

Guagua, Pampanga is mainly located in the southern part of the province, and it usually belongs to wetland areas. Based on the collected borehole data collected in the Unified Geotest Laboratory located in the City of San Fernando, Pampanga, the groundwater level was found to be relatively shallow. Additionally, the borehole was tested at Guagua, Pampanga, making the data more accurate for use in the study area. To start with the modeling of groundwater flow, a Topography Map and a Digital Elevation Map (DEM) for San Rafael, Guagua, Pampanga were prepared using ArcGIS. The aforementioned maps were utilized as input in the ModelMuse to generate a Model Top.

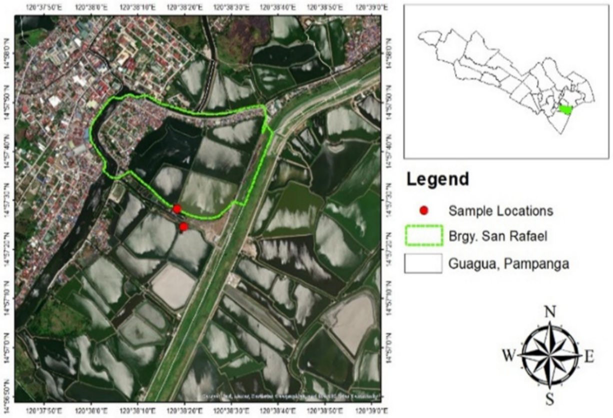

Fig. 1 Topography Map of Brgy. San Rafael, Guagua, Pampanga

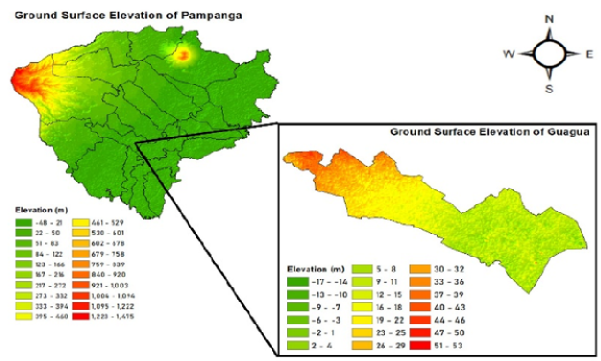

Fig. 2 Digital Elevation Map (DEM) of Pampanga

The generated results were utilized as inputs to create a groundwater table contour map for Guagua, Pampanga. The groundwater table contour map was created in ArcMap using the deep well inventory data collected by the researchers from the Local Water Utilities Administration (LUWA). This generated contour map was utilized as MODFLOW software's input to determine in what direction do the groundwater flow.

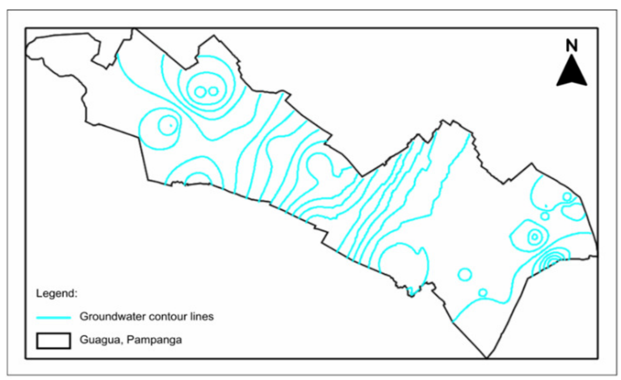

Figure 3. Groundwater Table Contour Map of Guagua, Pampanga

After creating a contour map delineating the groundwater table, the ModelMuse software package was utilized as a GUI in order to execute the codes in models such as MODFLOW and MT3DMS [13] was utilized. To generate results using ModelMuse, the DEM of Guagua, Pampanga was used as an input in the ModelTop. Afterward, the researchers identified the aquifer layers as confined and unconfined based on the borehole logs collected. Moreover, the package inputs such as the evapotranspiration package, recharge package, as well as the wells data were determined in order to simulate the flow of groundwater. In line with this, stress periods were also set in the software MODFLOW to determine the flow of water over 50 years.

The flow and direction of groundwater as shown in Figure 15 was utilized to determine the elevation of the water table in the study area, pinpointing where the higher elevation and the lower elevation of the study area.

C. Modeling of Groundwater Flow in MODFLOW

The actual model of the groundwater flow was created using the MODFLOW groundwater flow simulation model. The U.S. Geological Survey distributes the MODFLOW model as a popular open-source groundwater flow model that was widely used. In order to make the model more user-friendly and to address its limitations, various versions of MODFLOW have been developed because of the increasing interest in the interaction between surface water and groundwater, the need for localized refinement in nested grids that are unstructured, karst groundwater flow modeling, solute transport modeling and saltwater intrusion modeling [14].

In modeling the flow of groundwater, hydraulic parameters were considered. For the hydraulic conductivity, it was stated that the value ranges from 10^{-3} and to 10^{-5} [15]. For this study, the researchers considered the hydraulic conductivity to be 10^{-4}. Specific storage and specific yield were also considered, default values10^{-5} and 0.2 in MODFLOW were utilized. Additionally, longitudinal dispersivity (LD) with initial value of 10m was also used. Furthermore, default values for other parameters like diffusion coefficient with a value of 0.0002, vertical and horizontal transverse dispersivity ratio with respective values of 0.01, and 0.03 were used based in a study [16].

TABLE IV
HYDRAULIC PARAMETERS

Parameter	Value
Hydraulic conductivity	0.0001 m/s
Initial head	0
Specific storage	0.00001
Specific yield	0.2
Longitudinal dispersivity	10 m
Porosity	0.25
Aquifer layer type	Convertible
Diffusion coefficient	0.0002
Horizontal transverse dispersivity ratio	0.03
Vertical transverse dispersivity ratio	0.01

After specifying the hydraulic parameters, the defined study region and the area of the dumpsite were designated directly in the interface of ModelMuse in a shapefile format. Grid cells served as the fundamental units for inputting data and obtaining corresponding outputs. The study area had been divided into grids that were taken as 100 m × 100 m. In defining the groundwater table gradient, the water table contours were imported directly into the software.

The contour lines of the groundwater table were established using a time-variant defined boundary head utilizing the values of the indicated heads on the contour map that was made in ArcGIS using wells data obtained from the National Water Resources Board (NWRB). The study area was imported again and then, three boundaries were designated: the recharge boundary, the evapotranspiration border, and the top active layer. In solving and modeling of the groundwater flow model, the program also made use of the preconditioned conjugate-gradient solver.

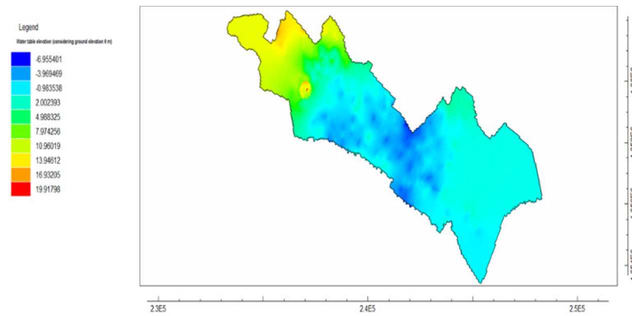

Fig. 4 Heads Observation representing Groundwater Flow

The elevation of the water table was found higher in the northwestern portion of the study area, and lower in the middle portion as shown in Figure 16. It shows that the flow of the study region's groundwater is towards the middle section of Guagua, Pampanga. The groundwater table fluctuated seasonally due to changes in demand, adding complexity to the modeling process. Therefore, the modeling was conducted without accounting for these seasonal effects. The only thing needed was to generate the water flow in ModelMuse that can be used to run MT3DMS.

D. Modeling of Contaminant Transport in MT3DMS

After modeling the groundwater flow in MODFLOW, the model of contaminant transport using MT3DMS was performed next. The modeling of contaminant transport was done for three (3) heavy metals (As, Cu, and Cr) that were traced in the groundwater. For each parameter, the MT3DMS software was utilized to predict the travel distance of each contaminant after 1,2, 5, 15, 25, 40, and 50 years.

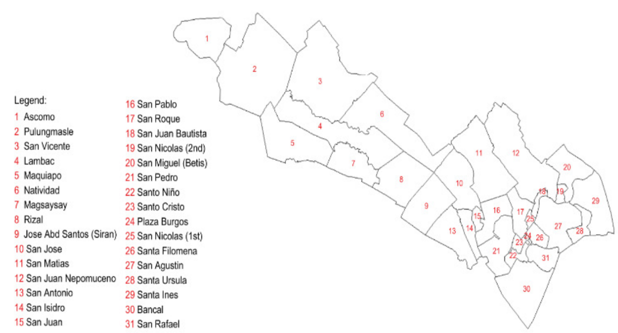

Fig. 5 Barangays in Guagua, Pampanga

Figure 5 illustrates the Barangays in Guagua, Pampanga. Guagua is composed of 31 barangays, thus, the numbers 1-31 represent every barangay within the area. The number 31 represents Brgy. San Rafael which is the area where the dumpsite is located.

1) Arsenic (As) Transport Modeling

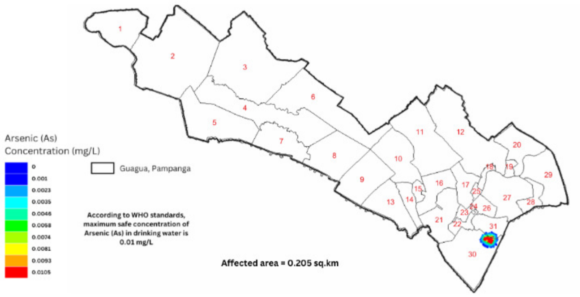

Fig. 6 Arsenic (As) Transport Modeling after 1 year

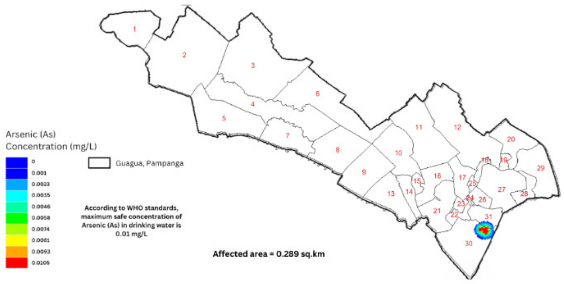

Fig. 7 Arsenic (As) Transport Modeling after 2 years

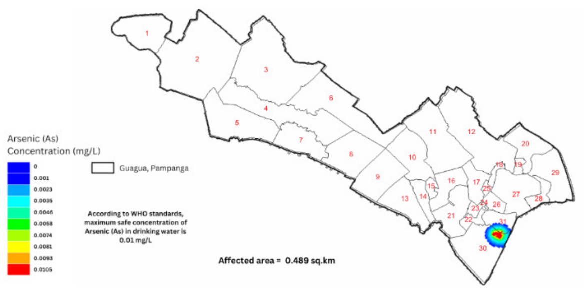

Fig. 8Arsenic (As) Transport Modeling after 5 years

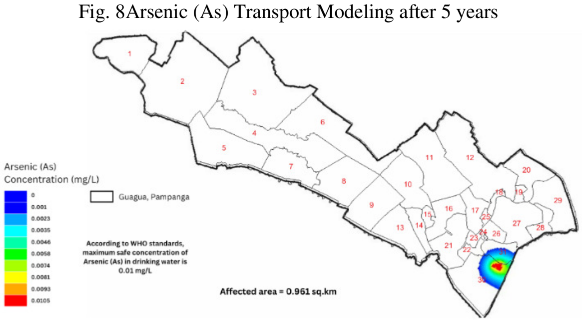

Fig. 9 Arsenic (As) Transport Modeling after 15 years

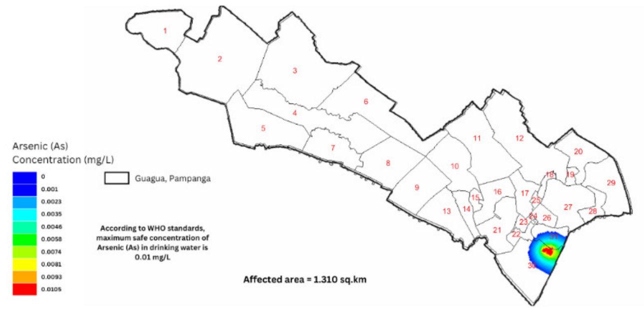

Fig. 10Arsenic (As) Transport Modeling after 25 years

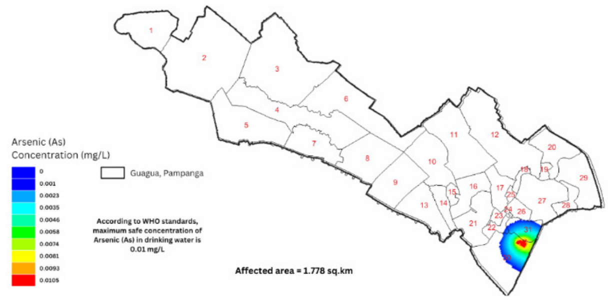

Fig. 11Arsenic (As) Transport Modeling after 40 years

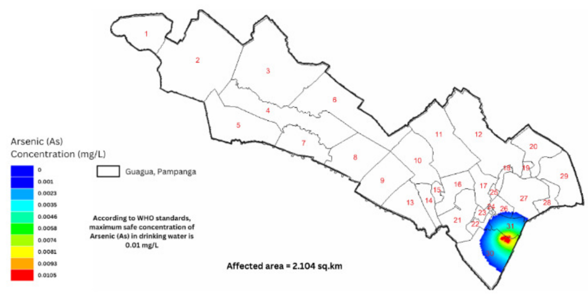

Fig. 12 Arsenic (As) Transport Modeling after 50 years

Figures 6, 7, 8, 9, 10, 11, and 12illustrate the transport and travel distance of As over a period of time. Due to the flow of As, the affected area after 1 year is 0.205 square km. After 2 years, the area affected is 0.289 square km. The next 5 years, the parameter As already reached an area of 0.489 square km. After 15 years, the contaminant reached and affected an area of 0.961 square km. For the 25th year, the contaminant already affected an area of 1.310 square km. During those years, the groundwaters affected were in the barangays San Rafael and Bancal only. For the 40th year, As affected an area of 1.778 square km. Finally, 50 years later, As started affecting the groundwater located at the barangays San Rafael, Bancal, Santo Nino, and portions of Santa Filomena and San Agustin with an area of 2.104 square km.

2) Copper (Cu) Transport Modeling

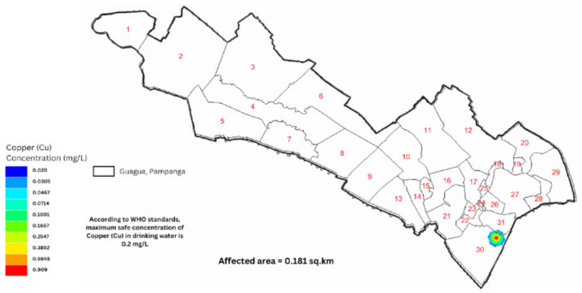

Fig. 13 Copper (Cu) Transport Modeling after 1 year

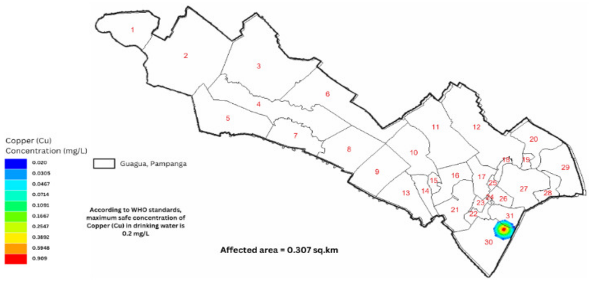

Fig. 14 Copper (Cu) Transport Modeling after 2 years

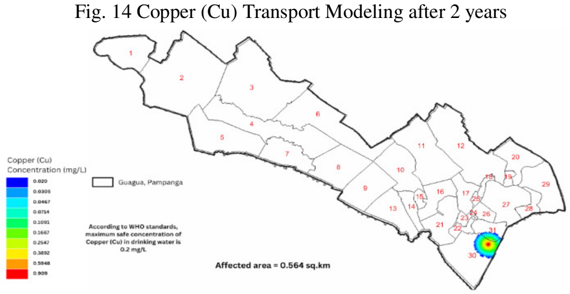

Fig. 15 Copper (Cu) Transport Modeling after 5 years

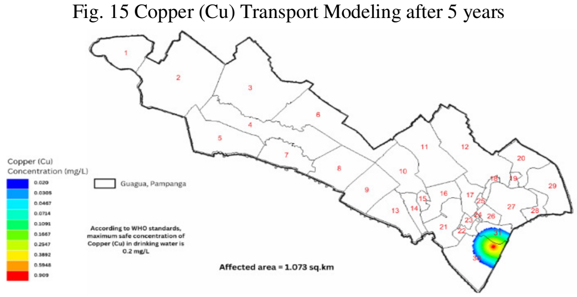

Fig. 16 Copper (Cu) Transport Modeling after 15 years

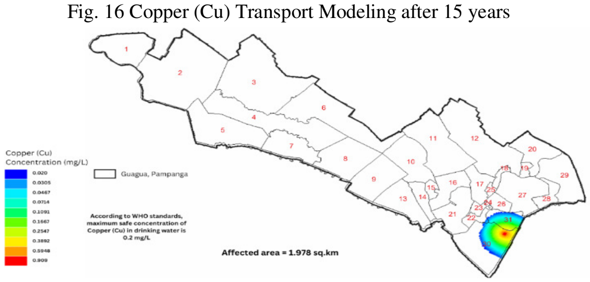

Fig. 17 Copper (Cu) Transport Modeling after 25 years

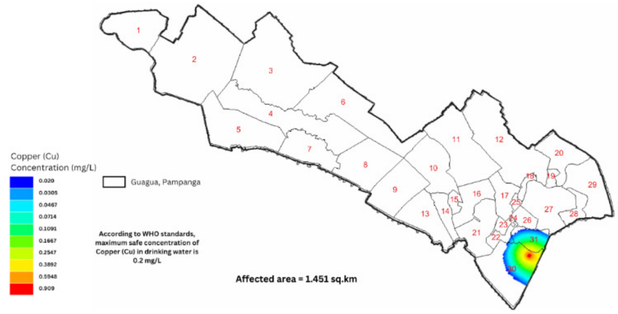

Fig. 18 Copper (Cu) Transport Modeling after 40 years

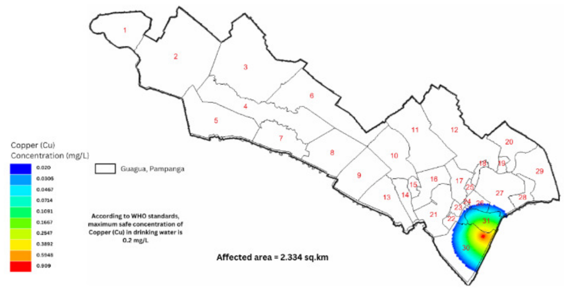

Fig. 19 Copper (Cu) Transport Modeling after 50 years

Figures 13, 14, 15, 16, 17, 18, and 19 illustrate the transport and travel distance of Cu over a period of time. In the 1st year, the area affected by Cu parameter is 0.181 square km. 2 years later, the area affected became 0.307 square km. 5 years after, the parameter Cu already reached an area of 0.564 square km. For the 15th year, the contaminant reached and affected an area of 1.073 square km. During those years, Cu contaminant affects only the groundwater of both Brgy. San Rafael and Brgy. Bancal. 25 years later, the contaminant is already at 1.451 square km, and it starts to affect Brgy. Santo Nino. For the 40th year, Cu affected an area of 1.978 square km. For the 50th year, the affected area is 2.334 square km and Cu starts to affect a large portion of the groundwater located at Brgy. San Rafael and Brgy. Bancal, and portions of the barangays Santo Nino, Santa Filomena and San Agustin.

3) Chromium (Cr) Transport Modeling

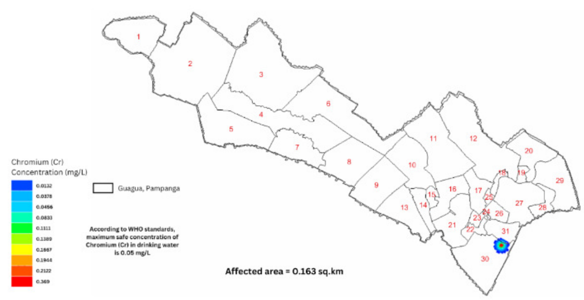

Fig. 20 C1hromium (Cr) Transport Modeling after 1 year

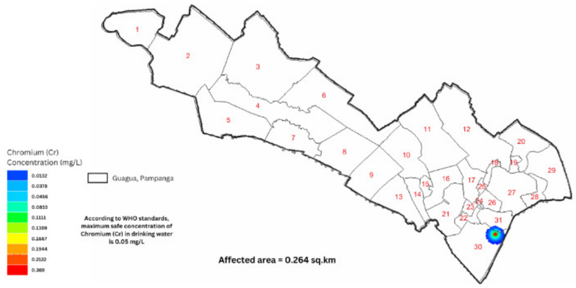

Fig. 21 Chromium (Cr) Transport Modeling after 2 years

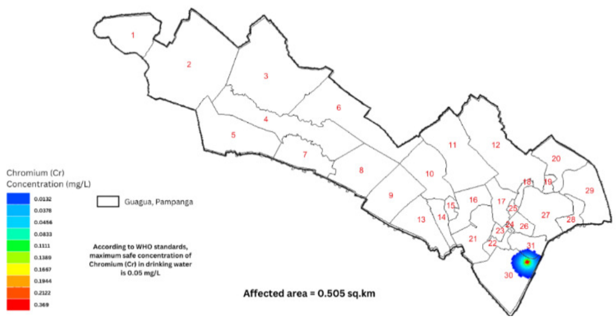

Fig. 22 Chromium (Cr) Transport Modeling after 5 years

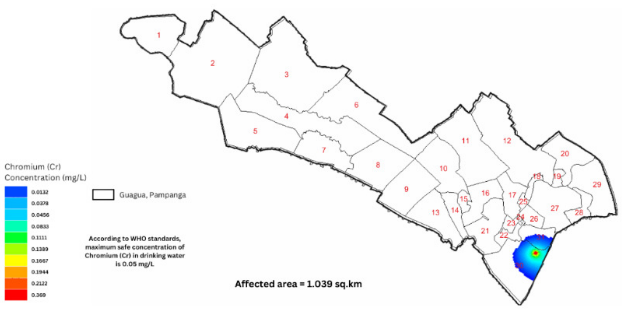

Fig. 23 Chromium (Cr) Transport Modeling after 15 years

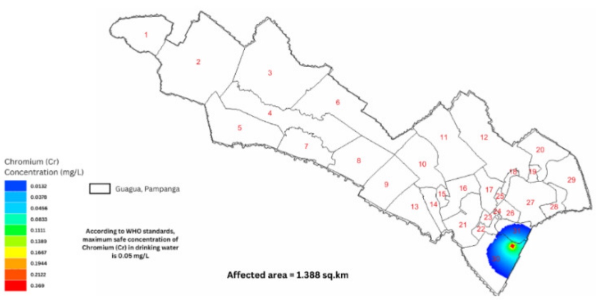

Fig. 24 Chromium (Cr) Transport Modeling after 25 years

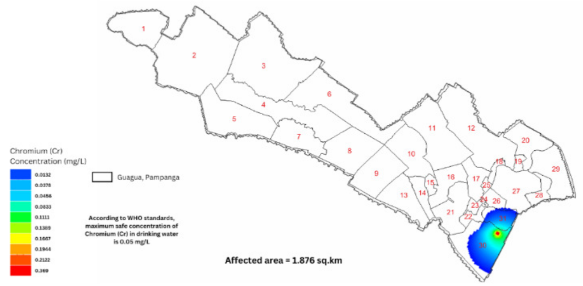

Fig. 25 Chromium (Cr) Transport Modeling after 40 years

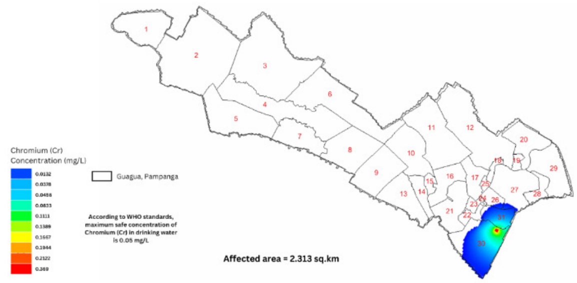

Fig.26 Chromium (Cr) Transport Modeling after 50 years

Figures 20, 21, 22, 23, 24, 25, and 26 illustrate the transport and travel distance of Cr over a period of time. Due to the flow of Cr, the affected area after 1 year is 0.163 square km. After 2 years, the affected area became 0.264 square km. 5 years later, the parameter Cr already reached an area of 0.505 square km. For the 15th year, the contaminant reached an area of 1.039 square km. During those years, Cr contaminant affects the groundwater of both Brgy. San Rafael and Brgy. Bancal only. 25 years later, the contaminant is already at 1.388 square km. For the 40th year, Cr affected an area of 1.876 square km. For the 50th year, the affected area is 2.313 square km and Cr starts to affect a large portion of the groundwater located at Brgy. San Rafael and Brgy. Bancal, with portions of the barangays Santa Filomena and San Agustin.

E. Model Projection Analysis

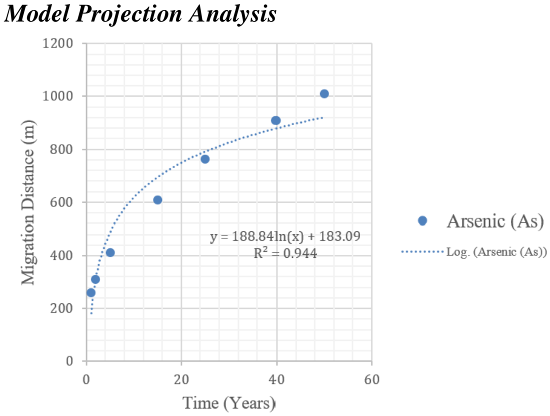

Fig. 27 Arsenic (As) Model Projection Analysis

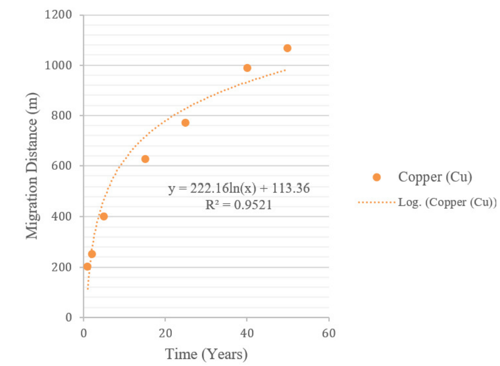

Fig. 28 Copper (Cu) Model Projection Analysis

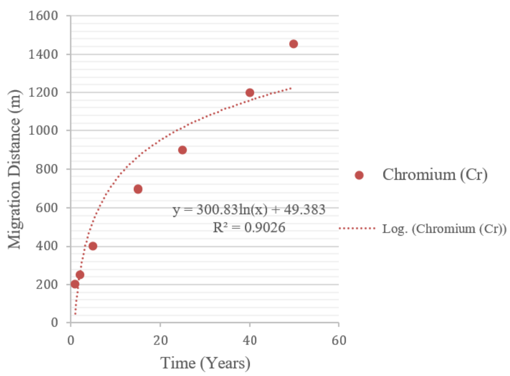

Fig. 29 Chromium (Cr) Model Projection Analysis

Figures 27, 28, and 29 provide a graphical depiction of the migration distance of the pollutants As, Cu, and Cr with respect to time. It was evident that the transport of contaminants varies with time. It can be observed that as time increases, contaminants start to dilute leading to the curve becoming shallow. This suggested that the contaminants may exist and remain in the environment for a longer period of time, and could influence future groundwater resources intervention policies and remediation strategies [17].

TABLE V
EMPIRICAL EQUATIONS

Parameters	Equation (Trendline)	R^2
Arsenic (As)	y = 188.84ln(x) + 183.09	0.944
Copper (Cu)	y = 222.16ln(x) + 113.36	0.9521
Chromium (Cr)	y = 300.83ln(x) + 49.383	0.9026

Table 5 shows the empirical equations for As, Cu, and Cr contaminants. The three equations generated from a trendline exhibit a logarithmic pattern, where the time in years started with 1 and above. It was observed that the R-squared value for the contaminants As, Cu, and Cr exceeded 0.9, this indicated that these equations are reliable and acceptable.

An equation can be formulated based on the given table:

$$y = A \ln(x) + B$$

Where:
y = migration distance of contaminants
x = time in years, which value is 1 and above
A and B = constants based on the concentrations of contaminants

F. Calibration and Validation of Models

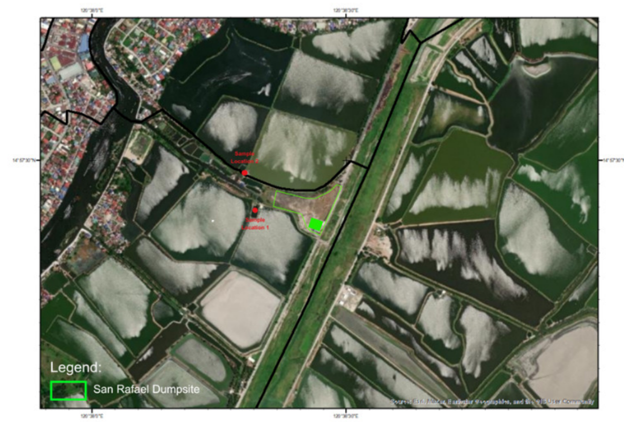

Fig. 30 Sample Location Points

In order to improve and authenticate the model's performance, a calibration and validation process was undertaken. This involved accurate laboratory tests on field samples collected from two locations: location 1, roughly 40 meters from the municipal dumpsite, and location 2, approximately 100 meters from the same site. The primary goal of this assessment was to compare the model's predicted accuracy against actual data. The first sample came from a deep well hand pump, which extracts water from a depth of 36.59 meters, while the second sample came from another deep well 91.46 meters below ground level.

In validating the model developed in this study, longitudinal dispersivity (LD) was found to be the most important calibration parameter in this study, as it significantly affected the behavior of contaminants during their transportation. LD controlled the direction and length of migration of contaminants in groundwater. Calibration was performed with a sample from location 1, aligning with laboratory test findings. This calibration process involved iterative adjustments to the LD parameter total dissolved solids (TDS) predicted by the model matched closely those measured at sample location 1. Following that, the LD value that was calibrated was used in the validation process, which corresponded to laboratory data from a sample obtained at location 2. The San Rafael municipal dumpsite in Guagua, Pampanga, has been operating for more than 25 years. As a result, it is expected that the Total Dissolved Solids (TDS) concentration will remain less than or equal to 1,000 mg/L [18].

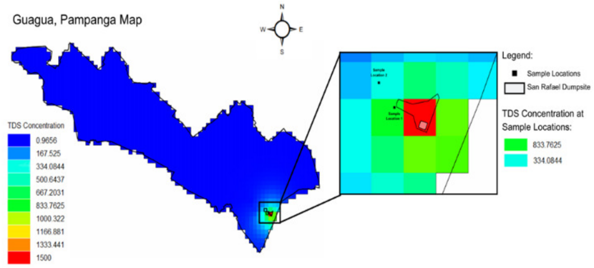

Figure 31. TDS Concentration at Sample Locations 1 and 2

TABLE VI
CONCENTRATION OF TDS (LABORATORY RESULTS AND MODEL PROJECTION)

Sample Location	Laboratory Results (mg/L)	Model Projection (mg/L)	Distance from the dumpsite (m)	Projection Error (%)
1	828	833.7625	40	0.696
2	332	334.0844	100	0.570

Figure 31 shows the discrepancy in Total Dissolved Solids (TDS) concentrations between the model's projection and laboratory tests, while Table 6 shows the tabulated results for TDS. Sample location 1 is most affected by dumpsite contaminants due to its proximity. As a result, the model's prediction closely matched the actual laboratory measurement of TDS concentration with a projection error of 0.696. Sample location 2, on the other hand, being considerably more distant, is anticipated to encounter additional sources of contamination beyond the dumpsite vicinity. However, owing to the remote nature of the municipal dumpsite, the model's forecasted TDS concentration at location 2 closely corresponds with the laboratory analysis outcome with a projection error of 0.570.

IV. SUMMARY AND CONCLUSIONS

A. *Summary of Findings*

The researchers conducted the study in order to simulate significant models that such as the flow of groundwater and the transport or movement of contaminants. The MODFLOW and MT3DMS are advanced modeling software that were utilized in assessing the groundwater condition and in examining the possible presence and expansion of contaminants in the sources of water.

In order to know and analyze the contaminants that were present in the groundwater source of the study region, a sample of leachate obtained in the dumpsite was tested in a laboratory. The results obtained from the laboratory test indicated that there were traces of heavy metal contaminants like Arsenic (As), Copper (Cu), and Chromium (Cr), with concentrations of 0.0105 mg/L, 0.909 mg/L, and 0.369 mg/L respectively. Additionally, water samples from the sources approximately 40m and 100m from the dumpsite were also subjected to laboratory testing and found that there were traces of contaminants in those areas.

In terms of the modeling of groundwater flow, a topography map and DEM were initially used in creating a groundwater contour map in ModelMuse. Afterward, the generated results from the ModelMuse were utilized in modeling the flow of groundwater in MODFLOW. In using the MODFLOW, the study area has been divided into grids with corresponding sizes of 100 m × 100 m. Grid cells were fundamental units used for inputting data and obtaining corresponding outputs. The output from the MODFLOW indicated that the elevation of the water table was higher in the northwestern portion of the study area and lower in the middle portion.

For the modeling of the transport of contaminants, MT3DMS software was utilized. The groundwater flow generated from the MODFLOW software was used in generating concentration and transport maps for the contaminants As, Cu, and Cr, for 1,2, 5, 15, 25, 40, and 50 years. For contaminant As, the affected area reached 2.104 square km after 50 years. For contaminant, Cu, the area affected reached 2.334 square km. Moreover, the contaminant Cr eventually reached 2.313 square km after 50 years. The contamination mostly affected the barangays San Rafael and Bancal, and reached portions of Santo Nino, Santa Filomena, and San Agustin. It was evident that the transport of contaminants varies with time. Based on the model projected analysis, it can be observed that as time increases, contaminants start to dilute, which means the contaminants may remain in the environment for a significant period time.

Lastly, for the calibration of the MODFLOW and MT3DMS, the model projected TDS was compared to the TDS of the two sample locations located approximately 40 m and 100 m from the dumpsite. The projected error for Location 1 was 0.696%, meanwhile, for Location 2, the projected error was 0.570%. This showed that the software can be utilized to accurately model real-world groundwater conditions.

B. *Conclusions*

The primary aim of the study was to model groundwater flow and the transport of contaminants in MODFLOW and MT3DMS. Initially, three heavy metal contaminants As, Cu, and Cr in the leachate sample were subjected to laboratory testing. The generated results indicated that the heavy metal parameters As, Cu, and Cr have concentrations values of 0.0105 mg/L, 0.909 mg/L, and 0.369 mg/L respectively. This indicated that the parameters As, Cu, and Cr have contributed significantly to groundwater pollution.

Based on the determined groundwater flow result that was modeled using the MODFLOW software, the elevation of the water table was found to be at a high level in the northwestern section of Guagua, Pampanga, while it was found to be lower in the middle section of the area, which confirms that the flow of the groundwater in the study region is towards the middle section.

After modeling the groundwater flow, the parameters As, Cu, and Cr were eventually modeled to assess their transportation and migration in the groundwater. Based on the concentration maps projected from the MT3DMS software, it was evident that as time increases, the groundwater areas that are being affected also increase.

In Figures 6 up to 26, it can be observed that the contaminants move toward the flow of the groundwater, which is the middle portion. Thus, the groundwater in areas that were located near the dumpsite and are along the groundwater flow are more susceptible to pollution and contamination [19].

Furthermore, based on the compared results between the model-predicted TDS and the TDS results of the laboratory-tested samples, it can be concluded that the software MODFLOW and MT3DMS can be utilized to model groundwater flow and predict the transport of contaminants.

V. RECOMMENDATIONS

After analyzing, thorough understanding of the data presented, and accomplishing the study, the researchers recommended the following:

- To lessen the contamination brought about by the leachate that penetrates the groundwater, it is recommended to design and construct an adequate liner system that will serve as a protective barrier between the piles of waste on the dumpsite and the underlying ground.
- The local authorities, as well as those who are in charge of collecting garbage from the barangays should implement strict segregation guidelines before taking away the trash from the houses, to reduce the potential of contamination. Accordingly, the dumpsite should be managed and monitored effectively and efficiently so that precautions will be taken, and the groundwater is protected from pollution.
- Proposing recycling and effective management techniques for solid waste, as well as policies that will make the residents well-informed about the risks and negative health impacts of the contaminants that may be generated from improperly disposed of garbage is also recommended.
- Additionally, products that contain various chemicals, especially those that contain high levels of As, Cu, and Cr, should be avoided. In line with this, using alternative products that are safe for the environment and beneficial to human health were recommended as it decreases pollution and contamination, and may reduce health risks and hazards.
- For future researchers who intend to utilize this study, it is recommended to model other heavy metal contaminants that may be present in the groundwater and assess their migration rate, pinpointing the puroks or barangays where the groundwater can no longer be a source of drinking water because contaminant concentration is high. Additionally, For MODFLOW, it is recommended to use monthly and up-to-date precipitation data and consider seasonal demands in modeling the groundwater flow. Moreover, for MT3DMS software, it is recommended to delve deeper and understand the effect of geological, hydrological, and climatic elements that may have an impact to the behavior and rate of contaminant transport.

REFERENCES

[1] M. Miguel, “Solid waste management.” https://www.denr.gov.ph/index.php/priority-programs/solid-waste-management

[2] B. P. Naveen, J. Sumalatha, and R. K. Malik, “A study on contamination ofground and surface water bodies by leachate leakage from a landfill in Bangalore, India,” International Journal of Geo-engineering, vol. 9, no. 1, Dec. 2018, doi: 10.1186/s40703-018-0095-x.

[3] Science Direct, “Pollution Control Technology for Leachate from Municipal Solid Waste,” ScienceDirect. https://www.sciencedirect.com/book/9780128158135/pollution-control-technology-for-leachate-from-municipal-solid-waste

[4] G. Akinci and A. Ozuysal, “Source identification of heavy metals and arsenic inbiodegradable fractions of municipal solid waste: a case study of Izmir metropolitancity,” Journal of Material Cycles and Waste Management, vol. 24, no. 1, pp. 386– 401, Nov. 2021, doi: 10.1007/s10163-021-01329-x.

[5] A. Kaana, “Evaluation of heavy metals in waste dumpsites,” Bsuportal, Mar. 2022, [Online]. Available: https://www.academia.edu/74754728/Evaluation_of_Heavy_Metals_in_Waste_Dumpsites

[6] M. G. Lak, M. Ghaffariraad, and H. J. Soureh, “Characteristics and Impacts of Municipal Solid Waste (MSW),” in Springer water, 2024, pp. 31–92. doi: 10.1007/978-3-031-52633-6_2.

[7] N. Vongdala, H.-D. Tran, T. Xuan, R. Teschke, and T. Khanh, “Heavy metalaccumulation in water, soil, and plants of municipal solid waste landfill in Vientiane, Laos,” International Journal of Environmental Research and Public Health/International Journal of Environmental Research and Public Health, vol. 16, no. 1, p. 22, Dec. 2018, doi: 10.3390/ijerph16010022.

[8] World Health Organization: WHO, “Arsenic,” Dec. 07, 2022. https://www.who.int/news-room/fact-sheets/detail/arsenic

[9] R. Manne, M. K. M. M. Raja, R. S. R. Iska, A. Devarajan, and N. Mekala, “Water quality and risk assessment of copper content in drinking waterstoredin copper container,” Applied Water Science, vol. 12, no. 3, Feb. 2022, doi: 10.1007/s13201-021-01542-x.

[10] M.-N. Georgaki and M. Charalambous, “Toxic chromium in water and the effects on the human body: a systematic review,” Journal of Water and Health, vol. 21, no. 2, pp. 205–223, Dec. 2022, doi: 10.2166/wh.2022.214.

[11] “Chromium | ToxFAQsTM | ATSDR.” https://wwwn.cdc.gov/TSP/ToxFAQs/ToxFAQsDetails.aspx?faqid=61&toxid=17

[12] “Water Quality Guidelines and General Effluent Standards of 2016,” EMB-Pollution Adjudication Board, Jun. 2016. https://pab.emb.gov.ph/wp- content/uploads/2017/07/DAO-2016-08-WQG-and-GES.pdf (accessed Apr. 28, 2024).

[13] “ModelMuse: a Graphical user interface for groundwater models | U.S. Geological Survey.” https://www.usgs.gov/software/modelmuse-a-graphical-user-interface-groundwatermodels#:~:text=Overview%20of%20ModelMuse&text=This%20software%20package%20provides%20a,independent%20of%20the%20stress%20periods

[14] J. D. Hughes, C. D. Langevin, and E. R. Banta, “Documentation for the MODFLOW 6 framework: U.S. Geological Survey Techniques and Methods,” book 6, chap. A57, 40 p., https://doi.org/10.3133/tm6A57.

[15] R. Maurya, A. Chandel, and U. Kumar, “Comparative Study of Various Soils UponAddition of Different Materials on the Basis of Hydraulic Conductivity Parameter,” May 2016. https://www.researchgate.net/publication/303364727_Comparative_Study_of_Various_Soils_Upon_Addition_of_Different_Materials_on_the_Basis_of_Hydraulic_Conductivity_Parameter

[16] J. Nyika, “Application of Experimental and Modelling Techniques to Estimate the Effects of Landfill Leachate on Soil and Water,” Apr. 2021. https://www.researchgate.net/publication/353999283_Application_of_Experimental_and_Modelling_Techniques_to_Estimate_the_Effects_of_Landfill_Leachate_on_Soil_and_Water

[17] S. Garg and S. K. Singh, “Modeling of arsenic transport in groundwater using MODFLOW: A case study,” ResearchGate, Oct. 2016, [Online]. Available:

https://www.researchgate.net/publication/309398014_Modeling_of_arsenic_transport_in_groundwater_using_MODFLOW_A_case_study

[18] M. Lasagna, D. A. De Luca, L. Debernardi, and P. Clemente, "Effect of thedilution process on the attenuation of contaminants in aquifers," Environmental Earth Sciences, vol. 70, no. 6, pp. 2767–2784, Mar. 2013, doi: 10.1007/s12665-013-2336-9.

[19] S. Mukherjee, S. Mukhopadhyay, M. A. Hashim, and B. Sengupta, "Contemporary environmental Issues of landfill leachate: Assessment and Remedies," Critical Reviews in Environmental Science and Technology, vol. 45, no. 5, pp. 472–590, Nov. 2014, doi: 10.1080/10643389.2013.876524.