

# Identification of Permissible Landfill Sites at the District Level: A Case Study in the Tarkwa-Nsuaem Municipality of Ghana

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## Abstract

Municipal solid waste (MSW) management continues to present formidable challenges for urban areas in Ghana and other developing countries. One such challenge is the acquisition or provision of sites for landfill development as suitable alternatives to help solve the environmental pollution and health hazards that emanate from open dumping at inappropriate locations. This paper presents the steps and results of a GIS-based site selection method that explicitly accounts for groundwater vulnerability in addition to meeting existing regulatory requirements and policy guidelines by EPA and Municipal Authorities. A case study approach is adopted with the Tarkwa Nsuaem Municipality as the study area. Equipment used include a desktop computer, ArcGIS and Microsoft Office Software, Google earth, GPS receiver and field cameras. With the waste management needs of the study area and the regulatory requirement as bases, the necessary data sets were gathered and organised into a spatial database suitable for site selection analysis. The factors considered included proximity to rivers, roads, railways and settlements; land-cover type; slope; hydrogeology; and groundwater. The ArcGIS, was vital for the preparation of the spatial database, processing models and the generation of criterion and output maps and other analytical steps and results. The analysis tools and methods used include buffering, overlays, raster-vector conversion, boolean algebra and "model-builder". Ground water vulnerability map was included as one of the main criteria to preclude areas of high groundwater contamination risk from the candidate sites. The methods and final results which indicate both the prohibited and permissible sites are available to support improved waste disposal efforts in the study area. The paper recommends the method for use by waste management departments in TNMA and other similar areas and that groundwater vulnerability analysis should be included in the site selection process as demonstrated in this paper.

**Keywords:** Permissible Areas, Regulatory Requirements, Criteria, Map Overlay, Model Building, Tarkwa

## 1 Introduction

Ghana, like other similar developing countries in Africa and the world over, is seriously plagued with several municipal waste management challenges such as increasing volumes of waste generation, low levels of waste collection, crude waste disposal practices, high environmental sanitation problems and inadequate acceptable final disposal sites and facilities (Kwesi et al, 2018; Anon. 2002, ). There has therefore been increasing concerns and demands for sustainable solutions to the rising municipal waste management problems. Based on an estimated population of 20 million and an average daily waste production per capita of 0.45 kg, Ghana generates about 3.3 million tons of solid waste annually (Anon, 2002). These quantities may double by the next decade. A high percentage of these volumes of waste are being

disposed off without adequate protection from the nuisance and harm caused to the environment and public health. One area that has been identified as having the potential for improving waste disposal in developing countries, is the use of engineered landfilling. This was a major reason that necessitated the development of the Landfill Guidelines (LG) by the Environmental Protection Agency (EPA) of Ghana and other countries (Anon., 2010; Anon., 2002). Amongst other functions, the guideline was to provide the basis upon which Environmental Permits and Certificates for land operations would be issued and renewed by the EPA and other related Local Authorities like the Metropolitan, Municipal and District Assemblies (MMDAs) in the country. Meeting these permit requirements start with the identification of candidate sites that meet regulatory requirements for locating landfills and

other waste disposal facilities. The guidelines entreat all MMDAs to identify, acquire and secure such sites for current and future use; so as to eliminate or reduce the perennial lack of appropriate final disposal sites for effective waste management. Unfortunately, this has not been embarked upon in a number of MMDAs (Anon. 2002, Kwesi, *et al.*, 2018). One way to support the addressing of this need is the provision of a simple practical step by step scientific method of carrying out the complex site screening and selection exercise to meet the requirements described in the guidelines. Thus the objective of this paper is to present and demonstrate the application of survey and mapping and GIS in a simple and practical approach for addressing the site screening need, using the Tarkwa-Nsuaem Municipality of Ghana as a case study area.

### 1.1 Geographic, Economic and Geological Background of Study Area

The study area is the Tarkwa Nsuaem Municipal Area (TNMA) with Tarkwa as the administrative capital (Fig. 1). It is located in the Western Region of Ghana between latitudes 4° 50' N and 5° 25' N and longitudes 1° 45' W and 2° 15' W (Fig. 2). TNMA has an area of about 950 km<sup>2</sup> and a population of about 90,477 (Anon., 2014). Tarkwa is a famous mining centre that attracts many people from other parts of the country, Africa and the world. Many of the big mining operations in the country are located in and around Tarkwa (Kusi-Ampofo and Boachie-Yiadom, 2012; Kuma and Ewusi, 2010; Anon, 2009). The economy of the area thus revolves around mining and its allied services. It is also an important commercial and transit centre linking the western and coastal towns to other parts of Ghana, and travelers from Cote d'Ivoire to Burkina Faso (Hlorvor, 2012; Kwesi, *et al.*, 2014). These factors draw many people to the city daily to look for jobs and do business. Some of these people settle, giving rise to rapid urbanization with a high population growth rate of about 3.0%. One direct social impact of this is the huge volumes of waste generation that is beyond the resources and capabilities of the Municipal Assembly to handle effectively (Kwesi, *et al.*, 2014; Anon., 2014).

The topography of the study area is generally undulating with some scarps ranging from 150 - 300 meters above sea level (Mantey, 2014; Hlorvo, 2012). Small scale mining operations frequently take place along these ridges and valleys (Anon, 2009, Asante, 2011; Adjei *et al.*, 2012; Kusi-Ampofo and Boachie-Yiadom, 2012). Geologically, the area forms part of the Birimian and Tarkwain formations. Aquifers in the area are considered possessing dual and variable porosity

and limited storage capabilities (Kuma and Ewusi, 2009; Asklund and Eldvall, 2005). Figure 2 shows the geological formations of the study area.

## 2 Materials and Methods Used

### 2.1 Materials

The materials used for the study include relevant information from literature, secondary data comprising criteria information, maps and related information on topography, geology, hydrogeology, soil, land-use and land-cover, utility and communication lines, climate and administrative and property boundaries; primary data comprising field coordinates, photographs, observations and interviews; and data capturing, processing and analyses equipment like GPS receivers, cameras, scanners, computers and their associated software and accessories. The data sources include Landsat ETM+ images of 2015, the US Geological Surveys (USGS.com), Google Earth, government and private organisations dealing with/related to waste management issues (such as EPA, MMDAs, TCPD, Land Commission, High Ways Authority, Forestry Commission, Geological Survey Department, Mineral Commission and Meteorological Services) and private data vendors and experts. The Digital Elevation Model (DEM) for the slope analysis was obtained from ASTER Global DEM (GDEM) and the soil data from maps published by FAO ISRIC. The software used include ArcGIS (10.4 and 10.5) and Microsoft Office Suite (2013 and 2016).

### 2.2 Methods

General methods used include literature review on waste disposal and site selection for municipal waste management including that must be met; data collection from relevant sources such as remote sensing images (USGS.com) and land use maps from Geomatic Engineering Department of UMaT and legal requirements and criteria for landfill site selection from waste management office of expert, and land-cover information; shape-files on topographic maps; processing the data into spatial database using ArcGIS software and steps; and spatial analysis using "Model Builder" in ArcGIS for the site selection and evaluation. A number of criteria were considered based on established guidelines from Ghana Environmental Protection Agency (GEPA) available datasets. Table 1 gives examples of the criteria.

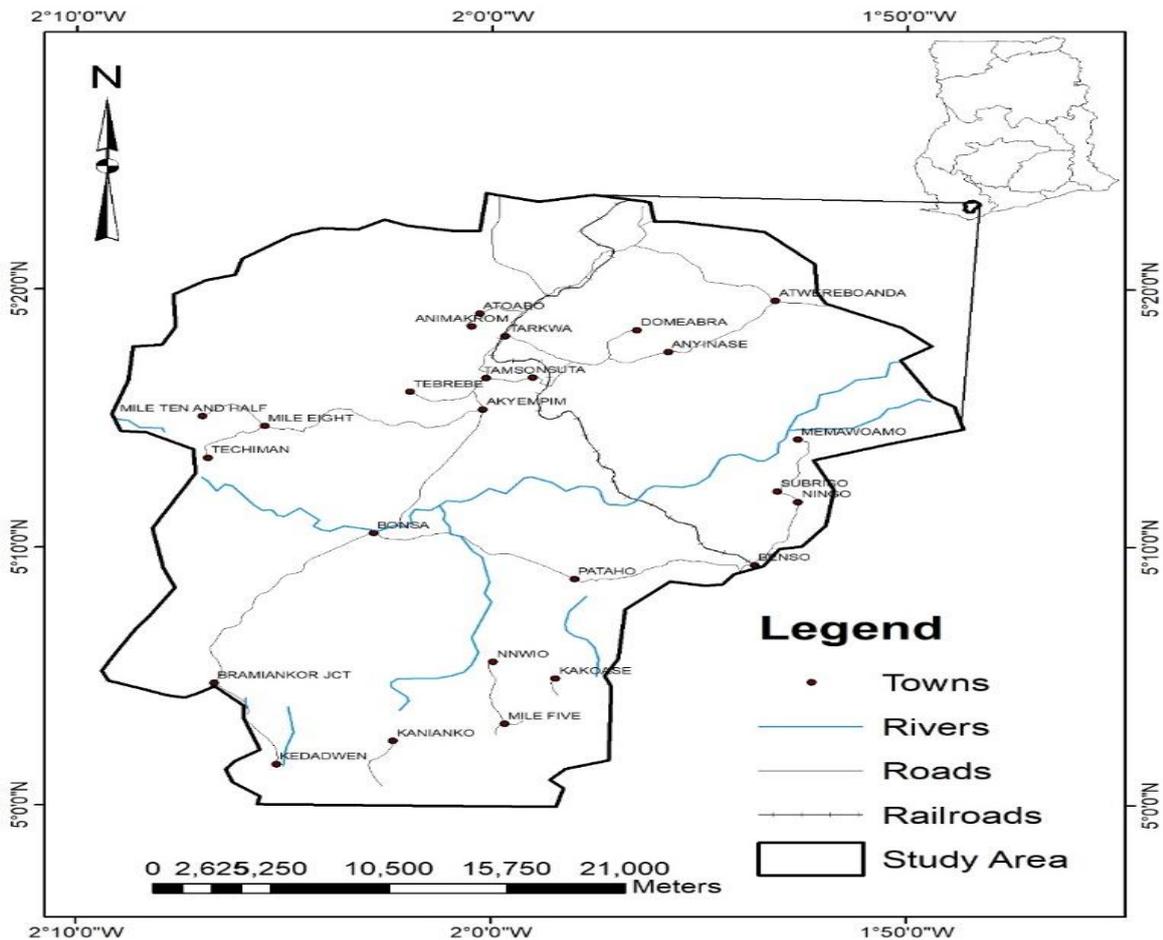


Fig. 1 District Map Showing Study Area

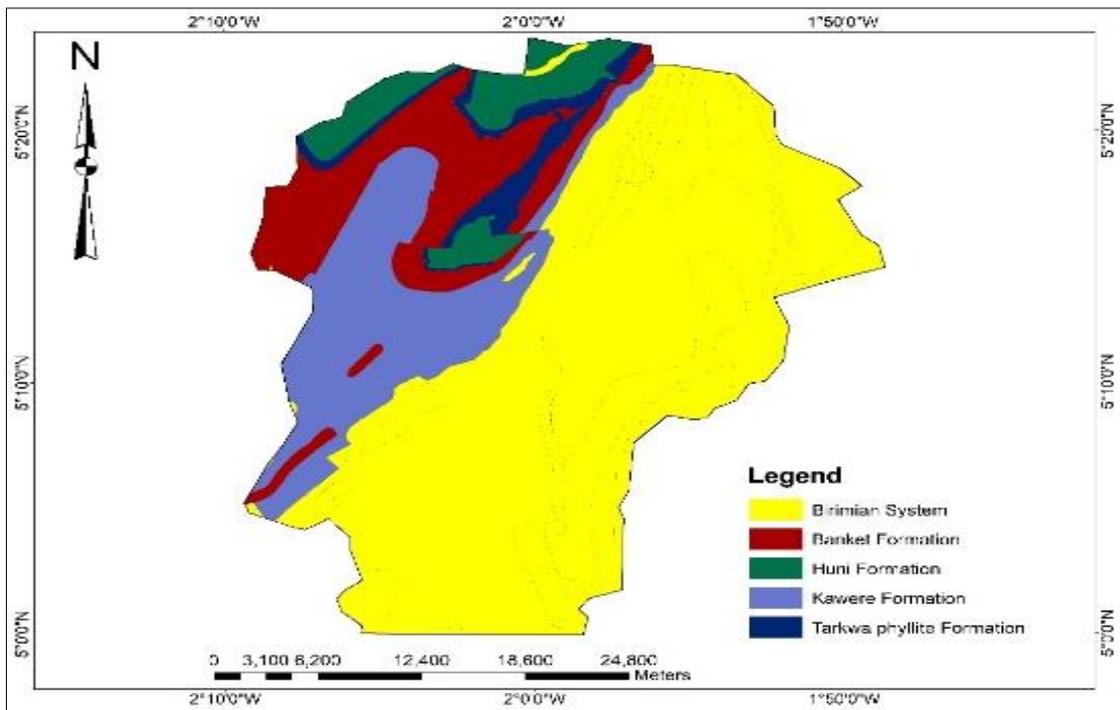


Fig. 2 Map showing the Geology of TNMA

**Table 1 Sample of the Site Selection Criteria and Buffer Zones Used**

<b>Criterion Factors/Elements</b>	<b>Restrictions Related to Criterion Element Based on Regulatory Requirements</b>	<b>Criteria Applied</b>
Land Use (Residential Areas, Active Mining Sites, Cemeteries, etc)	Areas within 500 m of residential and other sensitive land-uses	500 m buffer for residential, 200 m buffer for cemeteries and 300 m for active mining areas.
Land-cover (cash crops/farms, forests/game reserves, etc.)	Areas within 300-500 m of reserves and other properties	300 m buffer
Surface Water Bodies	Areas within 90-360 m of rivers, lakes, ponds, dams, wells, and springs	400 m buffer was used for wells important and 500 m buffer around other important water bodies
Roads, Railways and Utility Lines (water, gas, power and telecom lines)	Areas within 100-200 m of public transport and import utility lines	200 m buffer
Airport Runways and landing strips	Areas within 3000 m from the end of airport runways and landing strips in direct flight paths and areas within 500 m of airport or airfield boundaries	3000 m buffer and 500 m buffer
Slope	Areas with slopes $\leq 2\%$ and $\geq 10\%$	slopes $\leq 2\%$ and $\geq 10\%$
Soil	Areas with shallow bedrock and little soil cover	Based on the geology and soil information of the study area, locations characterized by the Fluvisols soil groups were rated as unsafe and thus restricted for use.
Geology	Subsidence, fault, seismic, mining and other unstable areas	Based on the geological information of the study area, locations having the Banket Series (Phyllite, Quartzite and Conglomerate hosting gold mineralisation), as well as the Huni Sandstone Formations within the Tarkwaian system were rated as unsuitable and thus restricted for use.

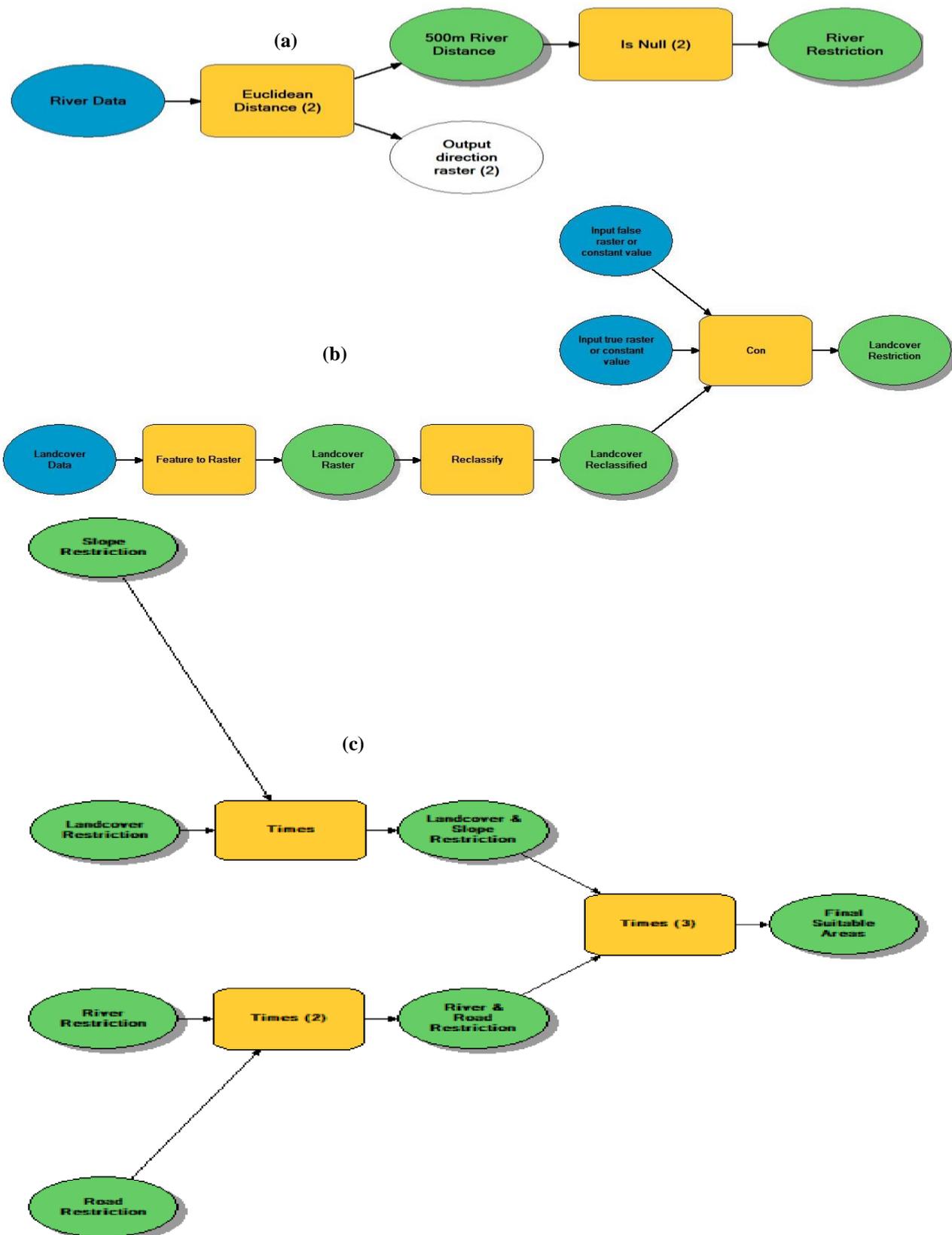


Fig. 3 Example of the Decision Processing Models for Linear, Areal and Integrated Features respectively for (a), (b) and (c)

The selection of permissible waste disposal sites was carried out through a model building process (Fig. 3). To facilitate easy understanding of the processing analysis, the modelling was fashioned separately according to the feature classes within the database, namely point, linear and areal features (Fig. 3 (a) and (b)). Also to meet the last segment of multi-criteria decision making process where the individual decision layers have to be aggregated into a resultant outcome, an integrated model (Fig. 3 (c)) was also employed for the combination of individual feature-based models into aggregation units. These four decision model classes were then applied to process and evaluate the decision variables based the various criteria employed in a step-by-step manner (feature by feature, feature-class by feature-class, and aggregate by aggregate) to yield the results presented and discussed in this paper.

### **2.2.1 Data Conversion, Processing and Analysis**

The data available for the work were of different formats and sources. These were converted into one uniform format. Thus those in vector formats were converted into raster formats in line with the demands of the analysis models and software used for the work. Reclassification of the layer's value were done into (1's) and (0's) scoring system, where "0" represented unsuitable and "1" signified suitable outcome. Buffering was done on various layers to determine values to assign suitable or unsuitable, for example, river was buffered by 300 m and areas within the buffer were assigned a value of 0, while areas outside were assigned the value of 1. Overlay of generated buffer maps were done in order to identify sites that were permissible and sites that were not permissible for landfill. ArcGIS (10.4 and 10.5) was used for the processing.

All the data layers were then entered into the model builder and thereafter converted to raster (grid) format from where buffering for the constraint mapping were carried out. After this, classification and union of all the buffered layers were done within the model builder. The model builder utilizes the weighted overlay procedure. In this process output maps are produced from various combinations of the multiple input data layers. The cells in the input map layers are assigned relevant weights to reflect the relatives importance of the criteria imposed before the layers are overlaid to produce the output maps. Figures 4 to 10 are examples of the output results from the data processing described in this section.

## **3 Results and Discussions**

Figures (Fig.) 4 to 10 show maps of analysis results based on the criteria applied for identifying permissible sites for municipal solid waste disposal in the study area. These are discussed in details in the subsequent sections under this.

### **3.1 Permissible Areas based on Surface Water Restrictions**

According to Ghana Landfill guidelines (2002), a landfill site should not be situated near water bodies such as rivers and streams, lakes, ponds and dams. A range of 90 m - 300 m is suggested in the guidelines depending on the type of water body and its relative importance. The location is a mining area where the effects of both legal and illegal surface mining activities on water bodies are already of a great concern to the general public with increasing threats of deteriorating water quality and subsequent health implications in the future. Fears of such threats will be heightened when waste disposal facilities are located in close proximities to the few major water bodies in the area. River Bonsa and its tributaries constitute the main water body in the area. Accordingly, 500 m buffer was used for the restriction. Using the ArcGIS (10.4 and 10.5) and its model builder function, the entire study area was segregated into two broad regions, those within the buffer zones classified as not permissible or unsuitable for waste disposal, and those outside the buffer zones classified as permissible for locating waste disposal sites. Within the permissible zones, areas lying between 500 m to 700 m from water bodies were classified as suitable and those beyond 700 m as most suitable use (Fig. 4).

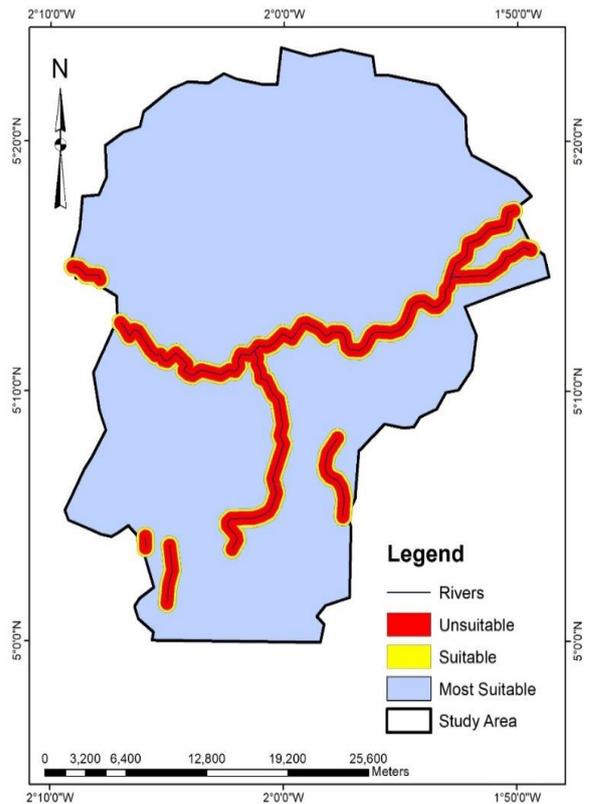
### **3.2 Permissible Areas based on Roads, Railways and Utility Lines Restrictions**

Landfills should not be located within 300 m of any roads so as to avoid the nuisance caused by birds and other scavenging animals crossing the roads. However, it is not also advisable to site the landfill too far away from existing roads, so as to avoid constructing new access roads and reduce travel time. Frequent break down of haulage trucks has been attributed to the poor nature of roads and with the site within a reasonable proximity to these major access ways the cost of maintenance could

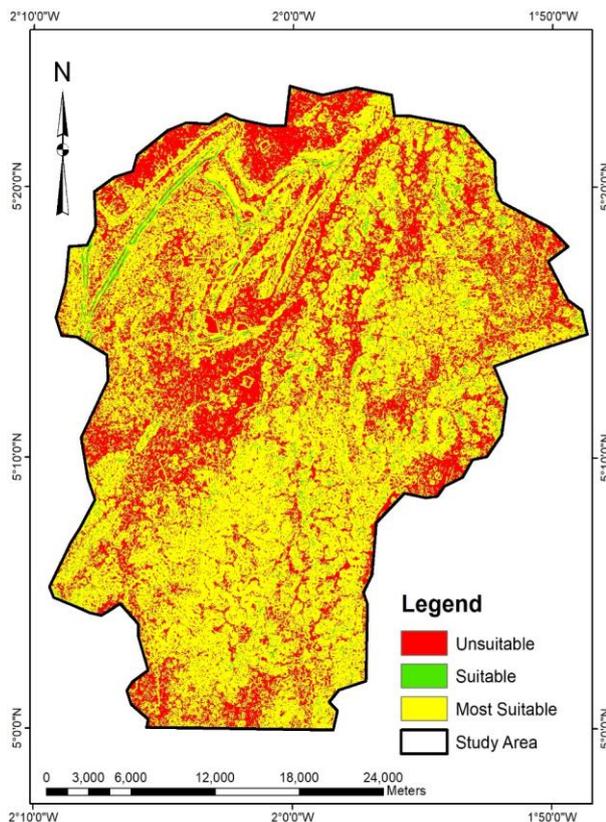
be reduced considerably. Within 300 m is restricted and unsuitable, between 300 m and 500 m is suitable and beyond 500 m is most suitable for siting a landfill as shown in Fig. 5 (Anon, 2012).

### 3.3 Permissible Areas based on Slope Restrictions

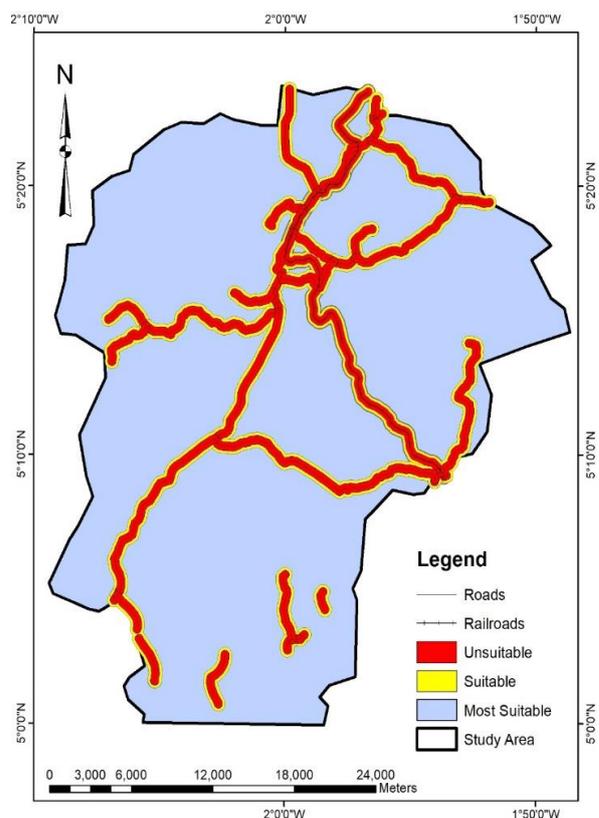
The slope of an area is one of the basic parameters considered when deciding on potential landfill sites. Areas having gradients greater than 10%, where stability of slopes cannot be guaranteed are not suitable for landfill. Areas with steep slopes (>10%) will have high runoff rates any time it rains. A higher runoff rate will lead to a decrease in infiltration thereby carrying contaminants as far as the runoff water can travel. The environment is then prone to contamination from the leachate and other toxic chemicals that will be carried away from the containment area by the runoff from the landfill, most especially, surface waters. In this study, areas with slopes between 2% and 10% were considered most suitable for the construction of a landfill and ranked 3, slopes between 10% and 15% were considered suitable and ranked 2 and areas with a slope less than 2% and greater than 15% were considered unsuitable and ranked 1. Fig. 6 shows areas determined for slope according to suitability.



**Fig. 4 Map Showing Permissible Areas Based on Criteria for Water**



**Fig. 6 Map Showing Permissible Areas Based on Slope Criteria**



**Fig. 5 Map Showing Permissible Areas Based on Road/Railroad/ Utility**

### 3.4 Permissible Areas based on Land-cover and Land-use Restrictions

Fig. 7a shows a map of the various land-cover/land-use classes considered for this work. Due to the presence of natural mineral reserves within the municipality, the population influx and growth is very high. The rate of expansion and development within the Tarkwa municipality is spreading very fast, so a reasonable buffer has to be determined for a landfill site so that it does not interfere with the developmental plans of the city. It is not advisable to site landfills in close proximity to Land cover areas such as farms, forest reserves, residential areas *etc.*; so as to avoid the adverse effects it would have on the economic value of the surrounding land as well as future development. This would protect the general public from possible health hazards arising from the operations of the facility. In this study, areas within 500 m from forest reserves were considered unsuitable and areas within 1000 m from villages/hamlets were also considered as unsuitable. Areas that were 2000 m away from settlements were considered most suitable for landfill as shown in Fig. 7b. Protection of the water bodies were considered separately in section 3.1.

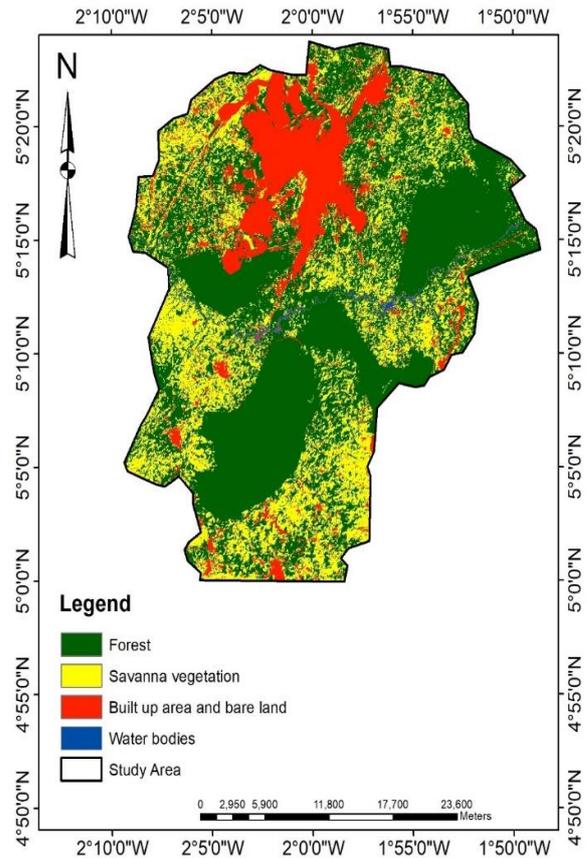


Fig. 7a Map Showing Land Use/Land Cover Categories

### 3.5 Permissible areas Based on Geology and Soil

Geologically (see Fig. 2), only a small part of the study area have locations considered to be unsafe and thus rated as restricted zones. These consist of Phyllite, Quartzite and Conglomerates hosting gold mineralization in the area. Figure 8 shows the results of the application of the restriction criteria on soil based on information from Table 1, Fig 2 the literature. The soil information of the study area is generally okay requiring no restrictions except a small narrow zone across the middle portions from west to east. This is made up of Fluvisols, comprising mainly of sandy and silt materials which together with the underlining geology make it a bit unsafe and thus rated as restricted zone. The remaining areas are dominated by acrisols and ferralsols consisting mainly of laterite and silt materials respectively rated as suitable and very suitable for use.

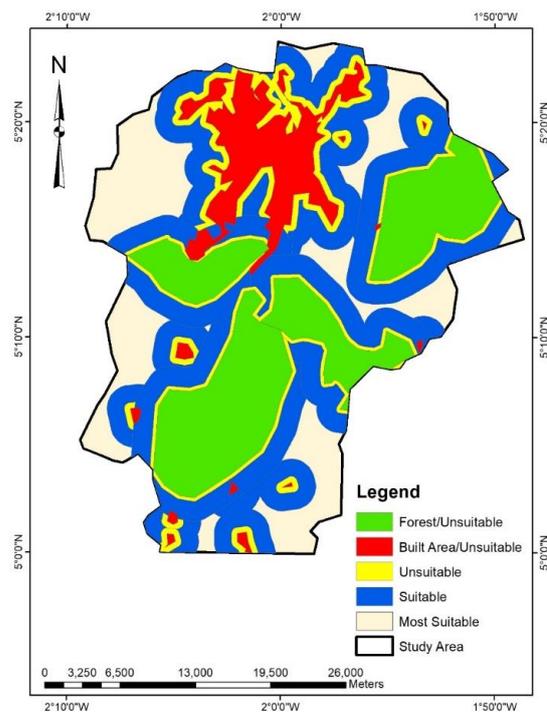


Fig. 7b Map Showing Permissible Areas Based on Landcover/Landuse CriteriaArea

### 3.6 Permissible Areas from All Restrictions

The composite suitability map was derived by running all the constraint maps based on the criteria (Table 1) using the Times tool in ArcGIS Spatial Analyst tool within the model builder. Fig. 9 shows this composite map showing the permissible areas from all the restriction criteria imposed on the search analysis according to the regulatory requirements and the related data available.

### 3.7 Overlay of Permissible Areas with Groundwater Vulnerability Map

To improve the reliability of protecting ground water from contamination, ground water vulnerability assessment was done and applied in the site identification analysis, though this is not explicitly stated in the regulatory requirements or guidelines. This is especially necessary for mining areas like Tarkwa where surface water bodies are already polluted and there is greater need to protect ground water for domestic and other uses (Yankey *et al.*, 2011; Asante, 2011; Kuma and Ewusi, 2010). The “DRASTIC” method of groundwater vulnerability analysis was employed and this was based on the seven major geologic and hydrogeological factors that control groundwater movement and pollution in the study area (Aller *et al.*, 1987; Rundquist *et al.*, 1991; Thapinta and Hudak, 2003; Al-Abadi *et al.*, 2014; Kwesi *et al.*, 2020). Fig. 10 shows the results of the groundwater vulnerability mapping indicating various classes of the risks of groundwater contamination. The final map of permissible areas at Fig. 9 was overlaid with the groundwater vulnerability map (Fig. 10) of the area to rule out all areas that have high risk of groundwater contamination if used for waste disposal. Figure 11 shows the results for this analysis.

From the map at Fig. 10, the high and very high groundwater vulnerability classes occur at the northern and northwestern parts of TNMA and occupies about 30 % of the study area. The moderate to very low vulnerability classes, constituting about 70% of the entire region, occupy mainly the western, central, southern and eastern parts of the region. Based on this information (Fig. 10), landfill sites situated in the northern and northwestern part of the study area, will have high to very high potential of contaminating the groundwater, and thus expected to be rated unsuitable in most of the cases. On the other hand, landfill sites situated in the western central, eastern and southern parts of the study area, will have moderate to low potential of contaminating the groundwater and thus expected to be rated suitable in most of the cases.

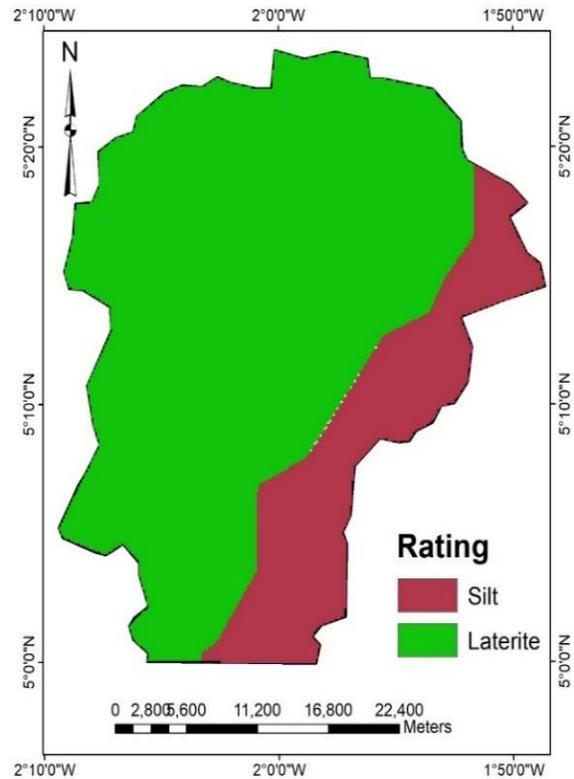


Fig. 8 Permissible Areas based on Soil

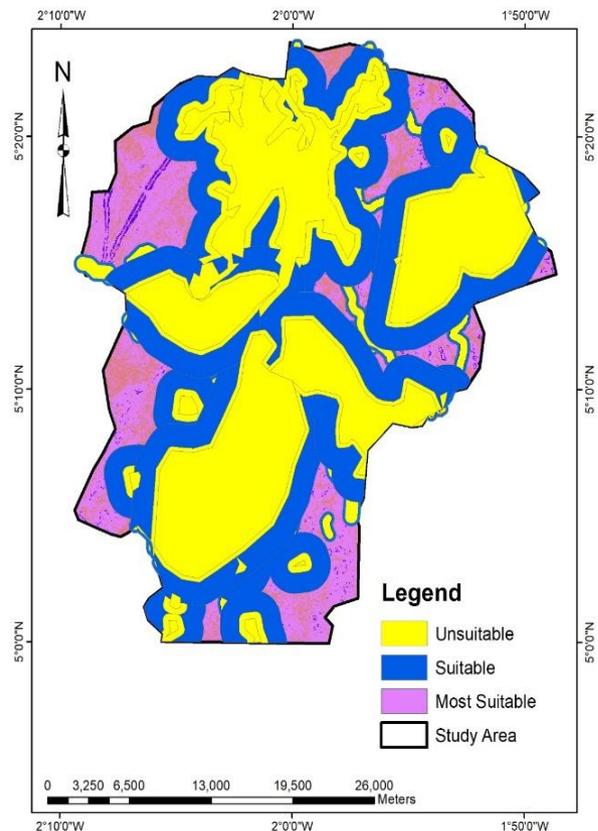


Fig. 9 Map Showing Suitable Areas Based on all Restrictions

These expectations are correctly reflected in the final site screening map at Fig. 11, proving the reliability of the simple but practical approach used for this exercise.

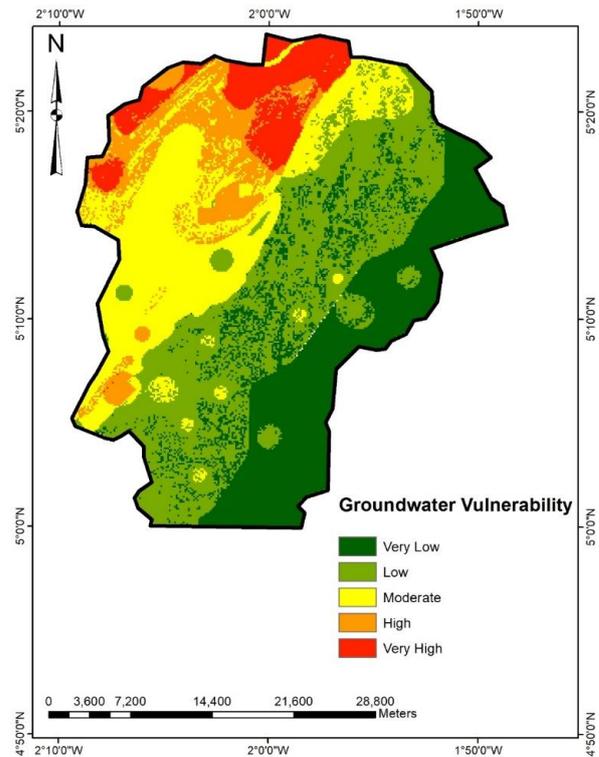
## 4. Conclusions and Recommendations

### 4.1 Conclusions

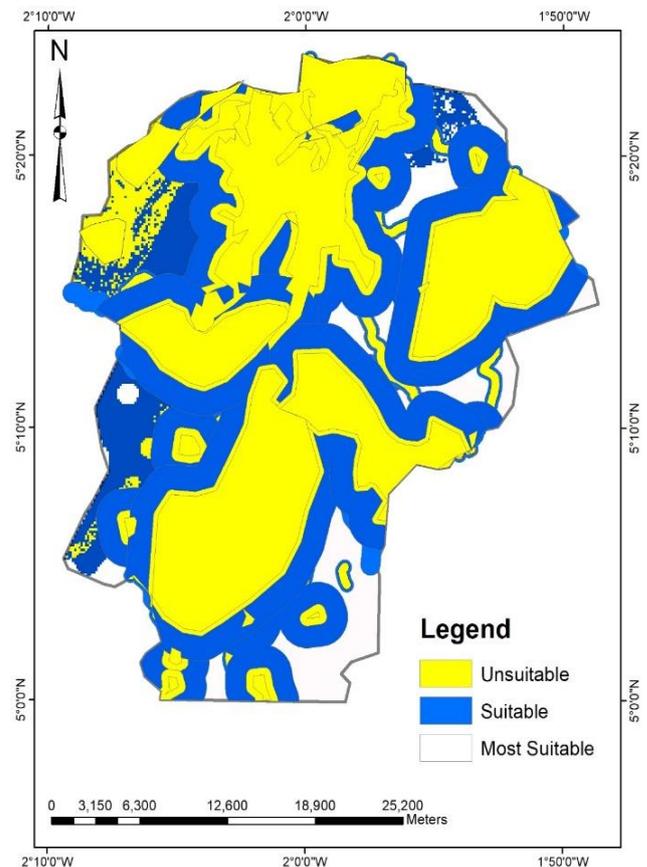
Meeting regulatory requirements in site selection for landfilling and other waste disposal facilities is an important and elaborate process that requires systematic analysis and evaluation of numerous factors, criteria and data from engineering, economic, environmental, socio-cultural and regulatory considerations. This study used Geographic Information System and spatial-based decision making models to identify permissible sites for landfill developments in the Tarkwa Nsuaem Municipality that meet regulatory requirements and explicitly accounts for groundwater vulnerability. The criteria used for the work was based on the regulatory requirements and guidelines from the EPA, MMDAs, and other Public and private bodies. The final composite map shows areas that are permissible and areas that are not permissible for landfill and other waste disposal development. The inclusion of groundwater vulnerability in the analysis is an important innovation to help reduce the risk of groundwater contamination. This is especially necessary for areas like Tarkwa and its environs where protection of ground water for domestic uses is increasingly becoming necessary since existing surface water bodies are being polluted by surface mining and related activities

### 4.2 Recommendation

It is recommended that groundwater vulnerability should be incorporated in the early stages of the site selection process to help reduce the risk of water contamination as demonstrated in this study. Also, due to some constraints with data availability, not all the legal requirements were used in this study. The results do not therefore reflect all the necessary criteria. Further work incorporating all the other legal requirements is recommended before accepting or using the results as sites that meet all legal requirements in the study area for actual work.



**Fig. 10 Map Showing Groundwater Vulnerability Model for Study Area**



**Fig. 11 Final Map of Permissible Sites based on Groundwater Vulnerability**

## References

- Adamović, V. M., Antanasijević, D. Z., Ristić, M.Đ., Perić-Grujić, A. A. and Pocajt, V. V., (2017), "Prediction of Municipal Solid Waste Generation Using Artificial Neural Network Approach Enhanced by Structural Break Analysis". *Environmental Science and Pollution Research*, Vol. 1, pp. 299-311.
- Aduah, M.S., Mantey, S., and Tagoe, N.D. (2012), "Mapping Land Surface Temperature and Land Cover to Detect Urban Heat Island Effect: A Case Study of Tarkwa, South West Ghana", *Research Journal of Environmental and Earth Sciences*, Vol. 1, pp. 68-75.
- Akyen, T., Boye, C. B. and Ziggah, Y. Y. (2017), "Landfill Lifespan Estimation: A Case Study", *Ghana Mining Journal*, Vol. 17, No. 2, pp. 1-5
- Al-badi, A. M., Al-Shamma'a, A. M. and Aljabbari, H. M., (2014), "A GIS-Based DRASTIC Model for Assessing Intrinsic Groundwater Vulnerability in Northeastern Missan Governorate, Southern Iraq", *Springer*, No. 7, pp. 89 – 101.
- Aller, L., Bennett, T., Lehr, J. H., Petty, R. H. and Hackett, G. (1987), "DRASTIC: A Standardized System for Evaluating Groundwater Pollution Potential Using Hydrogeologic Setting", *USEPA Report 600/2-87/035*, Robert S. Kerr Environmental Research Laboratory, Ada, 252 pp.
- Amankwah, R. K., Styles, M. T., Nartey, R. S. and Al-Hassan, S. (2010), "The Application of Direct Smelting of Gold Concentrates as an Alternative to Mercury Amalgamation in Small-Scale Gold Mining Operations in Ghana". *International Journal of Environment and Pollution*, Vol. 4, pp. 304-315.
- Anon. (2002), "*Ghana Landfill Guidelines*", Best Practice Environmental Guidelines Series No. 1 by Environmental Protection Agency (EPA), Ministry of Environment and Science, Ministry of Local Government and Rural Development, Accra, Ghana, 82 pp.
- Arkoc, O. (2014), "Municipal Solid Waste Landfill Site Selection Using Geographical Information Systems: A Case Study From Çorlu, Turkey". *Arabian Journal of Geosciences*, vol. 11, pp. 4975-4985.
- Asamoah, V.E., Asiam, E.K. and Kuma, J. S. (2009), "Management of Acid Mine Drainage at Tarkwa, Ghana", In *Appropriate Technologies for Environmental Protection in the Developing World*, pp. 199-204.
- Asante, E. S. (2011), "Mining Activities in Obuasi and Tarkwa Pollute 262 Rivers, Plague Residents with Keratosis and Diabetes", <http://environmentalwatchman.blogspot.com/2011/08/mining-activities-in-obuasi-tarkwa.html>. Accessed 10, August, 2014.
- Aye, L. and Widjaya, E. R. (2006), "Environmental and Economic Analyses of Waste Disposal Options for Traditional Markets in Indonesia", *Waste Management*, Vol. 10, pp. 1180-1191.
- Babu, B. V. and Ramakrishna, V. (2000), "Mathematical Modeling of Site Sensitivity Indices in the Site Selection Criteria for Hazardous Waste Treatment, Storage and Disposal Facility", *Journal of the Institution of Public Health Engineers, India*, Vol. 1, pp. 54-70.
- Basu, N., Nam, D. H., Kwansaa-Ansah, E., Renne, E. P. and Nriagu, J. O. (2011), "Multiple Metals Exposure in a Small-Scale Artisanal Gold Mining Community", *Environmental Research*, Vol. 3, pp. 463-467.
- Cossu, R. and Raga, R. (2008), "Test Methods for Assessing the Biological Stability of Biodegradable Waste", *Waste Management*, Vol. 2, pp. 381-388.
- Frempong, V. E. (2013), "Municipal Solid Waste Management in Tarkwa Area council (TAC), Ghana", *International Journal of Sustainable Development and Planning*, Vol. 4, pp. 563-575.
- Khoshnam H. (2006), "Site Selection of Municipal Solid Waste Landfills Using Analytical Hierarchy Process Method in A Geographical Information Technology Environment in Giroft" *Iranian Journal of Environmental Health Science and Engineering*, Vol. 3, pp. 177-184.
- Guermoud, N., Ouadjnia, F., Abdelmalek, F. and Taleb, F., (2009), "Municipal solid waste in Mostaganem city (Western Algeria)". *Waste Management*, Vol. 2, pp. 896-902.
- Hamer, G., (2003), "Solid waste treatment and disposal: effects on public health and environmental safety", *Biotechnology advances*, Vol. 1, pp. 71-79.

- Khan, D. and Samadder, S. R. (2014), "Application of GIS in landfill siting for municipal solid waste", *International Journal of Environmental Research and Development*, Vol. 1, pp. 37-40.
- Kolekar, K. A., Hazra, T. and Chakrabarty, S.N., (2016), "A review on prediction of municipal solid waste generation models", *Procedia Environmental Sciences*, Vol. 35, pp. 238-244.
- Kuma, J. S. and Ewusi, A. (2009), "Water Resources Issues in Tarkwa Municipality, Southwest Ghana", *Ghana Mining Journal*, Vol. 11, pp. 37-45.
- Kumar, S., Bhattacharyya, J. K., Vaidya, A.N., Chakrabarti, T., Devotta, S. and Akolkar, A.B. (2009), "Assessment of the Status of Municipal Solid Waste Management In Metro Cities, State Capitals, Class I Cities, and Class II Towns in India: An Insight", *Waste Management*, Vol. 2, pp. 883-895.
- Kusi-Ampofo, S. and Boachie-Yiadom, T. (2012), "Assessing the Social and Environmental Impacts of Illegal Mining Operations in River Bonsa", *Study Report, Business Sector Advocacy Challenge (BUSAC) and Pure FM, Tarkwa, Ghana*, pp. 7-17.
- Kusimi, J. M. and Kusimi, B. A. (2012), "The Hydrochemistry of Water Resources in Selected Mining Communities in Tarkwa". *Journal of Geochemical Exploration*, Vol. 112, pp. 252-261.
- Kwesi, E. A. A, Asamoah, K. N., Arthur, F. A. and Kwofie, J. A. (2020), "Mapping of Ground Water Vulnerability for Landfill Site Selection Assessment at the District Level – A Case Study at the Tarkwa Nsuaem Municipality of Ghana", *Ghana Journal of Technology*, Vol. 4, No. 2, pp. 57 - 65.
- Kyerematen, R., Adu-Acheampong, S., Acquah-Lampsey, D., Anderson, R. S., Owusu, E.H. and Mantey, J. (2018), "Butterfly Diversity: An Indicator for Environmental Health within the Tarkwa Goldmine, Ghana", *Environ Nat Resource Res*, Vol. 3, pp. 69-83.
- Miezah, K., Obiri-Danso, K., Kádár, Z., Fei-Baffoe, B. and Mensah, M. Y. (2015), "Municipal Solid Waste Characterization and Quantification as a Measure towards Effective Waste Management in Ghana". *Waste Management*, Vol. 46, pp. 15-27.
- Nishanth, T., Prakash, M.N. and Vijith, H. (2010), "Suitable Site Determination for Urban Solid Waste Disposal Using GIS and Remote Sensing Techniques in Kottayam Municipality, India". *International Journal of Geomatics and Geosciences*, Vol. 2, 197 pp.
- Onuigbo, I. C. and Bello, A. E., (2014), "Assessment and Selection of Suitable Sites for Solid Waste Disposal using Surveying and Geoinformatics Techniques", *International Journal of Engineering Research and Technology (IJERT)* ISSN, pp. 2278-0181.
- Rundquist, D. C, Rodekohr, D. A, Peters, A. J., Ehrman, L. D. and Murray, G. (1991), "Statewide Groundwater-vulnerability Assessment in Nebraska Using the DRASTIC/ GIS Model", *Geocarto Int*, Vol. 2, pp. 51–58.
- Shekdar, A. V., (2009), "Sustainable Solid Waste Management: An Integrated Approach for Asian Countries". *Waste Management*, Vol. 4, pp. 1438-1448.
- Stem E., Bilintoh T. M. (2015), "Municipal solid Waste Landfill Site Selection in the Sekondi-Takoradi Metropolis of Ghana Using Fuzzy Logic in a GIS Environment: Case Study". *Journal of Environment and Waste Management*, Vol. 2, pp. 71-78.
- Thapinta, A. and Hudak, P. F. (2003), "Use of Geographic Information Systems for Assessing Groundwater Pollution Potential by Pesticides in Central Thailand", *Enviro Int.*, Vol. 29, No. 1, pp. 87–93.
- Wilson, M., Renne, E., Roncoli, C., Agyei-Baffour, P. and Tenkorang, E., (2015), "Integrated Assessment of Artisanal and Small-Scale Gold Mining in Ghana—Part 3: Social Sciences and Economics", *International Journal of Environmental Research and Public Health*, Vol. 7, pp. 8133-8156.
- Siddiqui, M., Everett, J. W., Vieux, B. E. (1996), "Landfill Siting Using Geographic Information Systems: A Demonstration", *Journal of Environmental Engineering*, Vol. 2, pp. 515–523.
- Yankey, R. K., Akiti, T. T., Osaе, S., Fianko, J. R., Duncan, A. E., Amartey, E. O., Essuman, D. K. and Agyemang, O. (2011), "The Hydrochemical Characteristics of Groundwater in the Tarkwa Mining Area, Ghana", *Research Journal of Environmental and Earth Sciences*, Vol. 3, No. 5, pp. 600-607.

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