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Geological and Geotechnical Considerations in EIA Studies of Geohazards Susceptible Projects: A Review

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Abstract: ***Environmentally progressive countries in the world require the conduct of an Environmental Impact Assessment (EIA) before the approval of any infrastructure project with substantial impacts on the environment to ensure sustainability. Potential problems are addressed before the implementation stage to prevent any degradation in the environment. One of these problems is the geological hazards that can pose threats to the environment and human lives if not mitigated appropriately. This study is a review and examination of scientific papers that integrate geological and geotechnical/ hydrogeological aspects in the EIA of engineering projects in geologically susceptible areas, such as power plants, waste facility, mining areas, flood structures and, oil and gas facility. The review reveals that the majority of engineering projects are not integrating geological and geotechnical aspects in their EIAs. The review also reveals that there are very limited studies that have been published about expanding or integrating geological and geotechnical aspects in EIA.***

Keywords: Geological, Geotechnical, Environmental Impact Assessment

1. Introduction

An Environmental Impact Assessment (EIA) study plays a vital role, and is a major prerequisite, in strengthening undertakings to prevent negative impacts, irreversible destruction and abuse of the environment of construction projects and activities. In most countries, it is a compulsory requirement for the approval of any infrastructure project with perceived substantial impacts on the environment [1]. If properly conducted, it ensures an improved and effective project implementation. Hence, the expertise and financial capability of companies and the government can be put to use in the formulation of a meaningful EIA [2].

In an ideal EIA assessed project, potential problems are addressed before the implementation stage to prevent any degradation in the environment. Among these potential problems are the geological hazards that can potentially threaten the environment and human lives if not mitigated appropriately. Geological hazards could negatively affect the value, integrity, and accessibility of a country’s assets. Several studies have been conducted that assessed areas with high susceptibility to geological hazards and evaluated the disaster resilience capacity of the communities within. By first quantifying the risk, the disaster vulnerability profile of a site can be derived which is important in hazard mitigation. With the help of appropriate strategies, hazard susceptibility can be minimized and the natural environment will be preserved [3]. Sometimes in the quest to maximize design performance, and minimize monetary costs, the potential adverse environmental impacts that are geologic or geotechnical in nature are not considered in the EIA process [4].

These geological threats include: compressible ground and shrink-swell soil, slope instability and landslides, ground dissolution, liquefaction and collapse, fluvial, coastal and groundwater flooding, aggressive ground conditions and mining hazard [5]. Mining activities if not appropriately practiced will pollute surface and groundwater systems and slowly affect other extensive areas [6], [7].

In the Philippine setting, the DENR Administrative Order No.28, Series of 2000 (DENR AO 2000-28) was issued on March 14, 2000. The said department administrative order (DAO) stipulates the inclusion of geological and geotechnical considerations in the EIA studies of geohazards susceptible projects. The DAO 2000-28 specifies an additional requirement for the issuance of the Environmental Compliance Certificate (ECC) to selected relevant projects. According to the DAO, all developers and project proponents of land development, subdivision and housing projects shall undertake the preparation of an Engineering Geological and Geohazard Assessment Report (EGGAR) [8], [9].

Being situated in the “Pacific Ring of Fire”, the Philippines is highly exposed to numerous forms of natural vulnerabilities. Many disastrous events have happened in the Philippines that have resulted in deaths and loss of property. Due to its peculiar geographic characteristics, the country is susceptible to numerous geological and hydrogeological hazards. According to [10], a phenomenon can be categorized into: a) geologic hazards if it is caused by subsurface geological process, b) hydrologic hazards if it is initiated by surface water action and c) hazards which are not directly caused by geological phenomena. Table 1 enumerates the hazards considered in the Engineering Geological and Geohazard Assessment (EGGA) implemented in the Philippines [10].

Table 1: General list of hazards considered in EGGA [10]

A. Geologic Hazard	B. Hydrologic Hazard
1. Fault related/ Seismic hazards	1. Fluvial
Ground acceleration	Flooding (overflow)
Ground rupture	Flooding (Sheetflow, concentrated run-off
Liquefaction	Scouring of riverbed
Differential settlement	Channel erosion and migration
Landslides	Rill erosion
Fault creep	Gully erosion
Lateral spread	Sedimentation
Tsunami	
Seiches	
2. Mass Movement	2. Coastal Hazards
Landslides	Flooding
➢ Fall	Coastal erosion
➢ Topple	Coastal aggradation
➢ Slump	Strom surge
➢ Slide	Coastal subsidence/ sea level rise
➢ Spread	Submarine landslide
➢ Flow	
➢ Complex	
Creep	C. Others
Subsidence	Air-borne
Settlement	Cosmic
3. Volcanic Hazards	
Lava flow	
Debris flow	
Pyroclastic flow	
Debris avalanche	
Lahar	
Lahar blast and pyroclastic surge	
Bombs and ballistic projectiles	
Ash fall	
Tsunami	
Flooding	
Volcanic gases	
Volcanic earthquakes	

This study is a review and examination of scientific papers that integrate geological and geotechnical/ hydrogeological aspects in the Environmental Impact Assessment of engineering projects (e.g., landfills, mining site construction, power plants, buildings or other construction activities) which are prone or susceptible to geological hazards. It aims to identify and determine gaps and highlight key findings in EIA integration.

2. Discussion

2.1 Integration of geotechnical/ geological aspects in EIA

Several authors conducted a study in integrating hydro-geotechnical aspects in EIA. One such case is in Delta State, Nigeria, wherein although EIA is used, the authors argued that an expanded study is necessary, providing relevant hydro-geotechnical information (e.g. groundwater flow directions) for an effective EIA. By integrating hydro-geotechnical information, the authors argue that "the effects of projects on the environment (water and soil) are properly evaluated and mitigated where necessary". Some studies demonstrated that typical geotechnical engineering methods can be integrated in the conduct of EIA such as the conduct of soil investigation and drilling up to 10m in depth, wherein soil and water samples were brought in the laboratory for analysis [11]. The authors posit that since geotechnical engineering procedures are the first that are being conducted in any construction process, they are very significant because they influence the sustainability of the engineering structure. Geo-structures (slopes, dams, retaining structures, foundations) are essential components of all infrastructures. The failure of these structures will undoubtedly pose threat and danger on the surrounding environment [12]. In reference to the result of the case study in Ogorode, Sapele, Delta State, Nigeria, it was revealed that the soil was fine-grained/ clay, with high plasticity overlying the aquifer. Flooding and erosion are the identified problems of the authors in the said area [11].

2.2 EIA in Hydropower Plant Projects

A case study for a Mini Hydropower project in Sri Lanka is considered in a study by [13]. The project incorporates geological aspects in the conduct of the EIA study. The main objective of the author is to identify the existing surface and subsurface geological conditions and describe the stability condition of the overburden soil and bedrock and identify geological hazards for the main structures in the power plant. Likewise, to recommend precautionary measures if ever there would be unfavorable geological conditions in the study area [13]. In this study, no clear methodology was stated. The results depended on interviews from the people around the area and field observations only. Nonetheless, they have determined the possible geological hazard of the project area. The authors have established that the project area was at moderate risk for a landslide. Additionally, the investigation has shown that exposed cuts during construction may lead to slope failures if left untreated. The bedrock was highly foliated and moderately jointed. The opening of joints and water leakage in the reservoir could occur due to some activities (such as blasting) if not properly executed [13].

2.3 EIA in Waste Facility Projects

Municipal Solid Waste (MSW) landfills are one of the engineering projects subject to geological hazards that need the integration of geological aspects in its EIA. MSW is a type of waste that is generated by humans on a day to day basis. They include liquid and gaseous wastes, garbage, industrial and agricultural wastes [14]. The geotechnical aspects considered in MSW landfill design include the overburden pressure due to the weight of the waste, settlement and bearing capacity of the soil [15]. In landfill siting, a broad understanding of the hydrogeological characteristics of the area is needed. One study discussed the importance of geophysical and hydrogeological techniques in identifying a suitable site for a waste facility [16]. The identification process includes the characterization of the sub-surface strata, location of the groundwater table and determination of the infiltration rates of the soil. A paper describes the environmental assessment process for the selection of solid waste disposal facilities for small communities [17]. The process proposes decision parameters for landfill development and fills the gap in EIA with the

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stepwise procedure forwarded by the authors. Another paper stated that although the EIA process can delay the construction of a landfill, it could result in a plan that is more environmentally friendly and sensitive [18]. The EIA process also provides the public with relevant information about waste management problems. One author argues that communities must remember that even when environmental conditions are good, there is still a chance that disaster can generate unimaginable losses when people are not prepared or informed about the impacts or risks of certain activities [3].

2.4 EIA in Mining Industry

Another necessary integration of hydrogeological aspects in EIA studies is in mining sites, with particular focus on the groundwater system. Mining provides livelihood and power generation among other benefits to mankind. Mining, however, leads to adverse changes in the quality of the air, water, and soil [19], [7]. Mineral exploitation has historically caused extensive impacts on the environment. There are several methods performed in the environmental assessment of mining projects. A research study identified the Folchi method coupled with the Takagi-Sugeno fuzzy neural network (TSFNN) to have been used in conducting EIA for mining projects [20]. Another method is an improved Analytic Hierarchy Process (AHP), also used for EIA in mining projects [19]. Their study shows that the impact on the geological environment is the primary factor that needs to be considered in the EIA. A study in Ghana [21] examined the coverage and inadequacies of hydrogeology guidelines in the EIA report by mining sites. The authors have found out that in Ghana, there is a strict requirement for the submission of EIA before mining lease concessions are awarded to mining companies. Mining companies are to conduct a sequential exploration model in the development of their mining sites. However, hydrogeological report guidelines are not adequately comprehensive in terms of inspection. There are EIA reports that contain no or little hydrogeological information. Oftentimes, the hydrogeological aspects were neglected in the report.

The conduct of the sequential exploration model for mining sites involves seven (7) phases which include: Desk studies, Regional reconnaissance, detailed survey, exploration drilling, outline drilling, evaluation drilling, and feasibility study. Though there was a robust implementation of EIA in mining sites in Ghana, there are many EIA reports that do not have the necessary groundwater information because essential data for assessment are not collected. Similarly, the study revealed the conduct of exploration for mining entails a significant or high expenditure for the project. The author argues that if the scope of EIA is expanded (including hydrogeological aspects), valuable benefits can be derived. As an example, the movement and quality of aquifers can be determined and water-rock interactions can be predicted [21]. Considering also the study of land subsidence in a mining area requires a thorough understanding of the geological, geotechnical and hydrogeological setting so that a proper plan of action could be implemented to mitigate the phenomenon [7]. Cost-wise, the aftermath of groundwater contamination will entail a more serious budget expenditure and environmental problem. [21].

2.5 EIA in Flood Mitigation Structure Projects

In the Philippines, the conduct of EIA is mandatory to all projects with perceived impacts on the environment. This includes flood mitigation projects which are generally categorized as Structural Flood Mitigation Measures (SFMM). There is a lack of information on the extent of compliance regarding the integration of EGGA reports in the impact assessment of geo-hazard prone projects in the country. One author put forward a method called Rapid Impact Assessment Matrix (RIAM) when conducting the EIA of SFMM projects [22]. The authors argue that the extant EIA procedure in the country is descriptive and qualitative in nature. The said method does not treat the biophysical and social-economic environment adequately according to the authors. The resulting EIA study concentrates on the impacts with little emphasis on the significance and scale of the project. The authors propose using or integrating other methods in the EIA, such as the RIAM for SFMM projects in Metro Manila to make the system more transparent and sensitive in the evaluation phase. The authors demonstrated the usefulness of the RIAM technique as a substitute or complementary activity of the EIA study. The RIAM technique "offers a simple yet effective means of identifying potential impacts in a transparent way which leads to a clearer and more meaningful EIA study" according to the authors.

2.6 EIA in Offshore and Gas Industry

In the offshore oil and gas industry, the EIA is already a standard component of the regulatory process in most cases [23]. However, despite the extensive implementation of EIA in the industry, there is little understanding of the contribution of EIA in protecting the environment. Author assessed the performance and quality of EIA in the oil and gas sector. The study determined the adequacy in the procedural practice and identified factors that affected the quality of the EIA outputs. Generally, the methodology consisted of a review of 35 Environmental Statements (ESs) and an interview with key authorities in the oil and gas industry. The ES is the primary device in reporting the environmental impacts and the legitimacy of offshore oil and gas operations. The study reveals that there are ESs with poor quality. There are ESs that have relatively good contents in the discussion of the project description and information and the baseline environment yet a thorough discussion in the impact evaluation/ identification, mitigation, and its significance is poorly lacking. However, the attempts to emphasize the need to ensure the offshore operations are economic and sustainable to improve environmental performance are worth noting according to the authors. In the scoping process, the authors point out that there is a "relatively weak scoping process since it is done by a relatively narrow group of participants". The authors suggest that for the EIA to be undertaken appropriately there should be a greater level of integration with the Strategic Environment Assessment (SEA) and the Environmental Management System (EMS). The authors further assert that there is a need to have an external evaluator or accreditor. Alternatively an EIA accreditation programme should be developed and added in the ES process; or perhaps, a more reasonable course of action, is the formation of an autonomous ES review committee to make sure that the regulatory requirements are complied with and to provide important comments and reactions on the quality of ESs [23].

The environmental management system in Myanmar is considered to be the lowest in the world [2]. They are still in the process of improving and revising policies and guidelines on environmental protection. The conduct of EIA is not strictly implemented, or at times conducted arbitrarily. Myanmar is rich in oil and gas resources. However, due to mismanagement, poor governance and the irresponsible conduct of the business sector these resources are not properly developed in the country. It is this context that author evaluated the performance and effectiveness of the implementation of the environmental management system in the oil and gas industry in Myanmar [2]. The author's methodology included the review and evaluation of local and other countries' EIAs and the setting of criteria to determine and obtain relevant data. Interviews were conducted and opinions were solicited from pertinent international agencies, professionals, and researchers. The result of the study shows that although the EIA system was well-designed, with the adequate and sound legal administrative framework, the guidelines are still "weak" and incomplete. Hence, the author argues that strengthening the policies and practices are needed to establish a well-developed and comprehensive EIA.

3. Conclusion

The inclusion of hydrological, geotechnical and geological aspects of susceptible areas in EIA studies is important. Hydro-geotechnical/ geological considerations will provide useful subsurface information that can be beneficial during the pre-construction and post-construction stages of geohazard prone project sites, providing invaluable insights into the decision making process. By incorporating hydrological, geotechnical and geological considerations in the EIA process, precautionary measures, appropriate environmental remediation, and protection can be integrated and implemented at an earlier stage, thereby minimizing ground disturbances and possible loss of life and property, resulting to sustainable use of natural resources. The implementation of engineering projects will not bring adverse impacts to the environment if there is a well-planned and systematic construction methodology that will be followed throughout the course of the project's construction and operational lifetime. Similarly, strict implementation and compliance of the policies and regulations of relevant authorities will help in saving the environment. Incorporating geological/ geotechnical aspects in EIA studies would almost certainly entail an additional cost to the project. Cost-wise, however, the repercussion of an environmental disaster (such as groundwater contamination) that could come up due to inadvertent neglect of geological/geotechnical considerations in the EIA of a project will result in a more serious budget expenditure and environmental problem.

For studies focusing on landfills, some aspects were not explained completely in the EIA report/s. This could be attributed to public resistance to the landfill construction. Landfill projects are, by nature, highly environmentally sensitive, oftentimes entailing multiple environmental and technical problems which include the geological/geotechnical hazards.

For studies focusing on mining exploration, the review shows that geological problem (water and soil) is the dominant factor in the conduct of the EIA. The review also revealed that generally, the common method employed in the EIA methodology in mining was the Analytical Hierarchy Process (AHP). Geological considerations are commonly considered in EIAs of mining projects.

Among the literature that has been reviewed (EIA for mining, power plants, waste facility, flood structures, and oil and gas industry), the lack of integration of geological aspects in flood structures and for oil and gas projects in their EIAs is obvious. Over-all, there are very few journals or published papers that deal with the integration of geotechnical and geological aspects for areas susceptible to geo-hazards in EIA. There is a gap in the literature, and perhaps in the compliance of EIA practitioners, in the incorporation of geological and geotechnical considerations in EIAs of projects relevant to EGGA.

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