Determination of the Most Suitable Location of Evacuation Center for a Flood-Prone Community Using Multi-criteria Decision Analysis: The Case of Barangay Sapang Bayan, Bulacan, Philippines

Charena P. Baluyot, Franz D. Santos, Clariz D. Santos, Hiyasmine S. Pili, and Allan R. Alzona

Abstract Damage brought about by natural calamities is often hard to anticipate because of its sudden and unexpected timing. There have been modern approaches such as Geographic Information Systems (GIS) that are now being explored to store, communicate, and display spatial data. Since engineering decisions often involve multiple factors to consider, the Analytical Hierarchy Process (AHP) as a Multi-criteria Decision Analysis (MCDA) method implies value judgment to come up with the best recommendations as solutions. Because of the unpredictability of natural calamities such as flooding and the extent of damage that they may bring, disaster risk management and planning have become important for communities across the world. This paper aimed to determine the most suitable location for an evacuation center for Barangay Sapang Bayan in Calumpit, Bulacan using GIS and AHP. The criteria that were considered and given weights were flood hazard parameters, flood risk parameters, and accessibility parameters. The weights that were used in overlaying the maps were generated using normalized values after the pair-wise comparison of each parameter. The results produced a suitability map showing that 8.98% of the study area is the most suitable locations for an evacuation center which can be found in places with far distances from the adjacent river and in areas of high elevation. Moreover, 25.86% of the total study area are suitable areas or can be considered evacuation center locations, and the rest of the barangay, 65.14%, was found to be the least to non-suitable locations. The findings of this study could aid planners and

C. P. Baluyot · F. D. Santos (✉) · H. S. Pili · A. R. Alzona
Department of Civil Engineering, National University—Manila, 1008 Manila, Philippines
e-mail: fdsantos@national-u.edu.ph

C. D. Santos · A. R. Alzona
Department of Environmental and Sanitary Engineering, National University—Manila, 1008 Manila, Philippines

officials in imposing mitigation measures and guide them in improving their disaster response in times of calamities.

Keywords Analytical hierarchy process · Bulacan · Flooding · GIS · MCDA

1 Introduction

Natural calamities have long affected communities due to the implications they bring to the economy in the aspects of agricultural production and infrastructure [1]. Severe disturbances like earthquakes, floods, and cyclones are considered disasters when they adversely and seriously affect human life, livelihood, and property [2]. Furthermore, the effects of these disaster to operations of society result in widespread human, material, or environmental losses [3]. Communities in coastal regions are the areas that are drastically affected and are more vulnerable to natural calamities [4]. Because of these effects of natural calamities, knowledge and information about the environment should be achieved [5] through the collection and processing of available data towards planning mitigating measures to lessen the risk that these natural phenomena would bring to communities.

Flood Mitigation should be considered where options such as engineering solutions and nature-based solutions can be applied [6]. Other approaches such as controlling from the storm water source can also be considered in managing flood problems of the community [7]. Another risk management strategy that is often an option during flood events is evacuation. Individuals that are displaced from their homes are transferred to Evacuation centers that provide shelter and safety from direct exposure to floods. Since floods can affect both life and property, proper monitoring and mitigation should be considered along with proposing possible solutions through flood risk management [8].

The disaster management community has been evolving over the past years. The use of modern technology has provided more specific disaster risk assessments, enhanced forecasts, minimized human losses with effective early warning systems, and strengthened resilience-building approaches of communities. In addition, the development of new approaches to disaster management may reveal various forms of collaboration, tools, techniques for gathering and managing data risks, communication, and knowledge-sharing approaches [9]. With the aid of technological innovations, people can better comprehend the intricacies of natural disasters that have atmospheric, geological, hydrological, and biological causes, analyze the transformation of these hazards into disasters [10] and provide a higher chance of survivability and safety during catastrophic events.

Geographic Information System (GIS) is a new emerging and powerful tool that collects, stores, retrieves, and analyzes geographic data. It can also be used in integrating various real-world geographic data elements [11] and displaying geospatial data [12]. Through databases on computer-generated maps, information sharing between all departments in one place is made possible. The use of GIS in assessing

the flood-risk of communities across the world had been explored [13–17]. However, the hydrologic response of an area varies depending on the topography, land cover, soil type as well as the climatic condition therefore saying that the flood risk of every community is different and must be assessed so that proper planning and management can be applied to the area.

Flood-risk management requires consideration of natural and man-driven factors [18] to come up with a more reliable direction for urban planning in cases of extreme storm events. Geographical data is combined with value judgements to arrive at appropriate tools for better decision-making [19] and this is known as the multi-criteria decision analysis (MCDA). GIS gives the spatial visualization of data while MCDA complements it by evaluating and prioritizing alternatives thus getting a better benefit from output and solution for spatial problems [20]. There are various techniques of value judgements that has been used in coupled GIS-MCDA studies [13, 19, 21] but among them, the Analytical Hierarchy Process (AHP) has been one of the most explored [22–27] because it is easy to understand and cost-effective [28, 29].

2   Materials and Methods

Site selection for evacuation centers is a crucial decision in disaster management as the location of the center can significantly affect the efficiency and effectiveness of the evacuation process. The use of GIS and MCDA as tools allow for integrating and studying various spatial and non-spatial data to determine the most suitable locations for evacuation centers. This paper aims to use a coupled GIS-MCDA methodology utilizing AHP in identifying a suitable location of an Evacuation Center of a flood-prone barangay in Calumpit, Bulacan.

2.1   The Study Area

Sapang-Bayan is a barangay in Calumpit, Bulacan, with a population of 3140, as recorded in the 2020 Census, accounting for only 2.65% of Calumpit's total population [30]. Figure 1 shows the location map of the chosen study area where the terrain was a shot from Google Earth.

Flooding is a persistent issue in Calumpit, especially in Sapang Bayan, where high tides and heavy rains often cause the river to overflow. During the recent typhoon (Typhoon Ulysses), the barangay experienced severe flooding with four to eight feet of water, making it one of the most affected areas in Calumpit [31]. The community faces three problems during typhoons: flooding, inadequate evacuation centers, and mobility difficulties. The proponents of this paper decided to focus on the problem of the lack of an evacuation center, as it is observed to be a problem for every family during a calamity since they have to evacuate in neighboring Barangay.
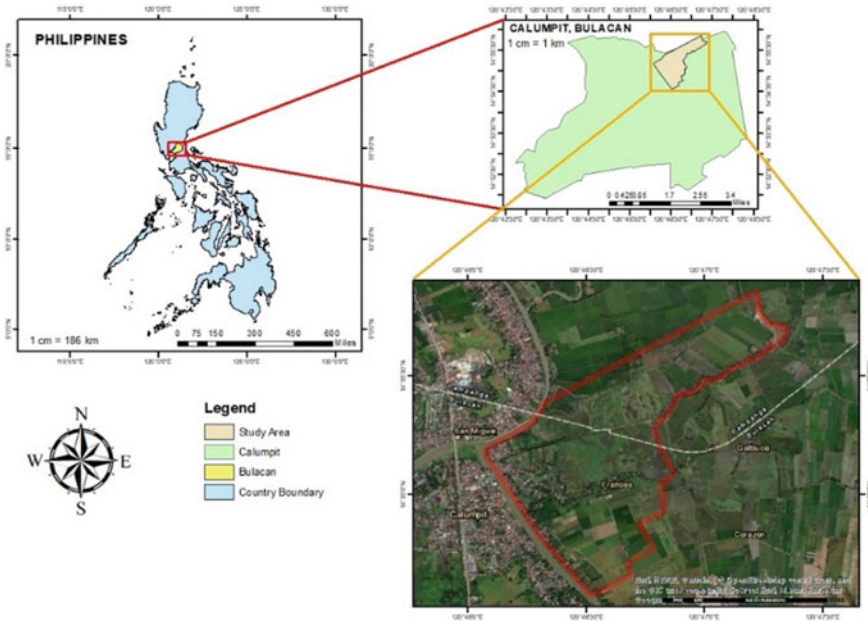
Fig. 1 Barangay Sapang Bayan in Calumpit, Bulacan

2.2 Data Collection

Data gathering is a very crucial phase in this study to arrive with the most suitable location of an evacuation center based on the different factors to meet the objective of this paper. In this site suitability study, the most desirable location for an evacuation center that will be safe from flooding was based on three criteria namely (i) flood hazard, (ii) flood exposure, and (iii) accessibility. In terms of flood hazard criteria, the following were considered as inputs: slope, elevation, soil type, and flood depth. For the flood exposure criteria: population density and land cover. And for the accessibility parameters, the following were considered: proximity to major roads and distribution of evacuation centers. Depicted in Fig. 2 is the framework used in the selection process.

2.3 Criteria Determination for Evacuation Center Site Selection

Three parameters were considered for Evacuation Center Site Selection: Flood Hazard Parameters, Flood Exposure Parameters, and Accessibility Parameters. They
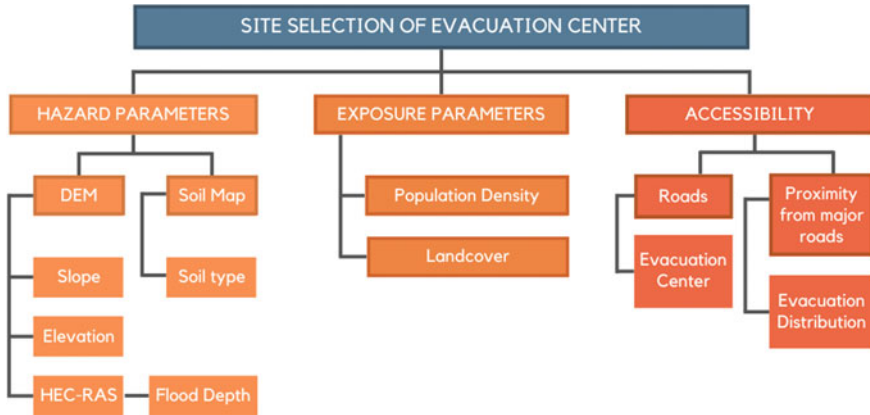
Fig. 2 Criteria-based site selection framework

are essential for ensuring that the evacuation center can meet the needs of evacuees and function effectively during an emergency.

Flood Hazard Parameters. The location to be selected should be away from potential flood hazards and structurally sound to withstand the hazard's potential impacts. Shown in Table 1, the identified flood hazard elements were slope, elevation, soil type, and flood depth. The Digital Terrain Model (DTM) came from the National Mapping and Resource Information Authority (NAMRIA) and the Soil Map was downloaded from the website of the Food and Agriculture Organization (FAO). Flood depth was generated from the flood inundation map that was simulated using the coupled Hydraulic Engineering Center—Hydrologic Modeling System (HEC-HMS) and Hydraulic Engineering Center—River Analysis System (HEC-RAS) for a 100-year storm (Table 1).

Flood Exposure Parameters. The exposure analysis was intended to identify the life and property elements exposed during flooding events. Population density and land use/cover in raster format were identified as exposure elements as shown in Table 2.

Accessibility Parameters. The site should be easily accessible to the population that will be evacuating and with adequate transportation available to reach the site. This may include proximity to major roads and highways and the availability of

Table 1 Flood hazard parameters and data used

Flood hazard parameters	Data type	Source	References
Slope	DTM	NAMRIA	[32–38]
Elevation	DTM	NAMRIA	[32, 37–39]
Soil type	Soil map of the world	FAO	[32, 33, 37]
Flood depth	Raster	HEC-HMS and HEC-RAS simulations	[37, 40]

Table 2 Flood exposure parameters and data used

Flood exposure parameters	Data type	Source	References
Population density	Raster	WorldPop Website	[32, 34, 36, 40]
Landcover	Raster	NAMRIA	[32–35, 37]

Table 3 Accessibility parameters and data used

Accessibility parameters	Data type	Source	References
Proximity to major roads	Shapefile	Geofabrik	[32, 33, 35–38]
Evacuation center distribution	Excel	DSWD/Google Map	[33–36]

public transportation. The identified accessibility elements were Proximity to Major Roads in shapefile format and Evacuation Center Distribution in coordinates as listed in Table 3.

2.4 Parameter Weighing Using Analytical Hierarchy Process (AHP)

GIS as a tool was used analyze and visualize data related to site selection for evacuation centers in Sapang Bayan, Calumpit. It was used to map the affected area, the population that must be evacuated, and the resources and infrastructure required at the evacuation centers. Location of possible site evacuation centers based on parameters such as flood hazard, flood exposure, accessibility, and suitability for the intended use was also assessed in this paper.

Pair-wise Comparison of Parameters. AHP was used to assess and compare the probable sites based on predetermined criteria such as slope, elevation, soil type, flood depth, population density, land cover, proximity to major roads, and evacuation center distribution. The AHP method involves breaking down the evaluation criteria into a hierarchy and assigning weights to each level to reflect the criteria's relative importance using Pairwise Comparison.

The normalized value for each criterion after pair-wise comparison was obtained and was used to calculate the weights that will be used in combining the layers. The potential sites are then evaluated based on these standards and weights shown in Table 4, and a final ranking of all the parameters is produced. This combination of ArcGIS and AHP allows for a systematic and comprehensive analysis of potential sites for an evacuation center in the area, helping to provide that the most suitable location is selected.

Table 4 AHP of all parameters

Flood risk parameters						
	Item description	Slope	Elevation	Soil type	Flood depth	Weight
1	Slope	0.27	0.27	0.27	0.27	26.9%
2	Elevation	0.23	0.23	0.23	0.23	22.9%
3	Soil Type	0.28	0.28	0.28	0.28	28.1%
4	Flood Depth	0.22	0.22	0.22	0.22	22.1%
Flood exposure parameters						
	Item description	Population	Land cover	Weight		
1	Population	0.50	0.50	50.1%		
2	Land cover	0.50	0.50	49.9%		
Accessibility parameters						
	Item description	Roads	Evacuation Center	Weight		
1	Roads	0.40	0.40	40.1%		
2	Evacuation center	0.60	0.60	59.9%		

3 Results and Discussion

Secondary data from the local government agency and other open-source websites were processed and analyzed according to the different criteria using ArcGIS. The map layers for each output are presented in this chapter.

3.1 Flood Hazard Parameters

Shown in Fig. 3 are the maps of parameters under flood hazard criteria. It can be noticed that based on the slope and elevation map, the areas that are more prone to flooding are the ones at the inner portions north-west. Due to a lower elevation ranging up to 0.90 m above mean sea level, it is expected that overflowing water from the river as well as runoff generated by storm events might come flushing down this area also because of the nature of the sloping terrain.

The soil map shows that the study area is made from Loam that may have an effect on the infiltration which is an important factor to consider in estimating and predicting overland flow [41]. The flood map generated from rainfall-runoff simulation of HEC-HMS and flood inundation mapping of HEC-RAS showed that the part of the study area adjacent to the river is the most prone to flooding with depths up to 2.1 m which makes the area not suitable for the construction of the evacuation center.
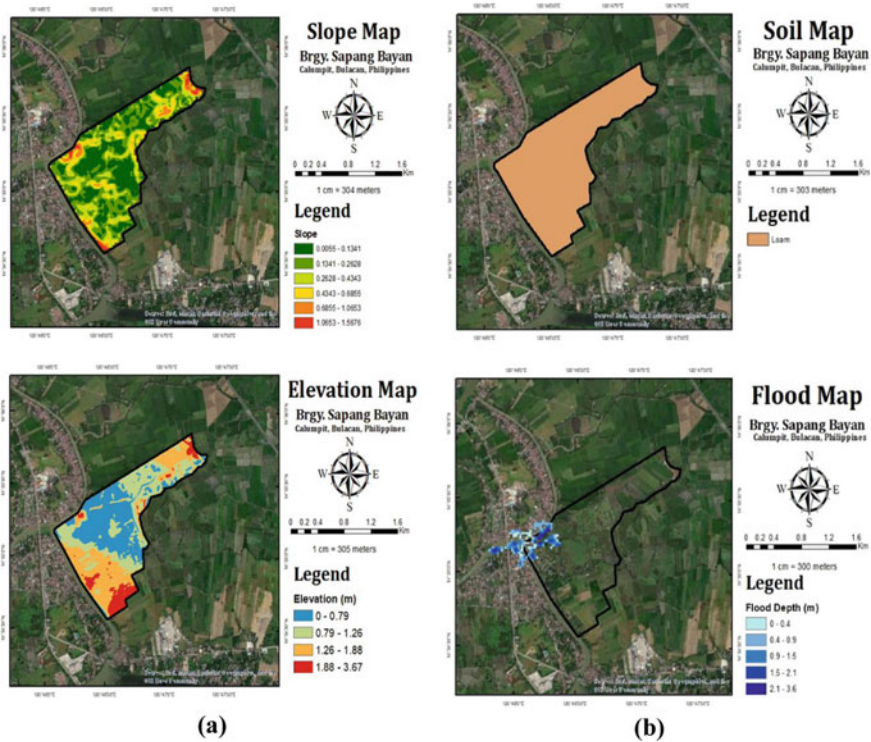
Fig. 3 Maps of study area considering flood hazard parameters **a** slope and elevation, **b** soil and flood map

3.2 Flood Exposure and Accessibility Parameters

Illustrated in Fig. 4 are the maps of the flood exposure parameters and accessibility parameters that were processed in ArcGIS. It can be seen on the population density map that majority of inhabitants are concentrated on the riverbank areas where they are of risk to flooding when an extreme weather event happens. Moreover, based on the location of evacuation centers in the area, no evacuation center is located within the boundary thereby strengthening the need for the objective of this paper that is to identify the most suitable location for an evacuation center considering the flood-prone nature of the area.
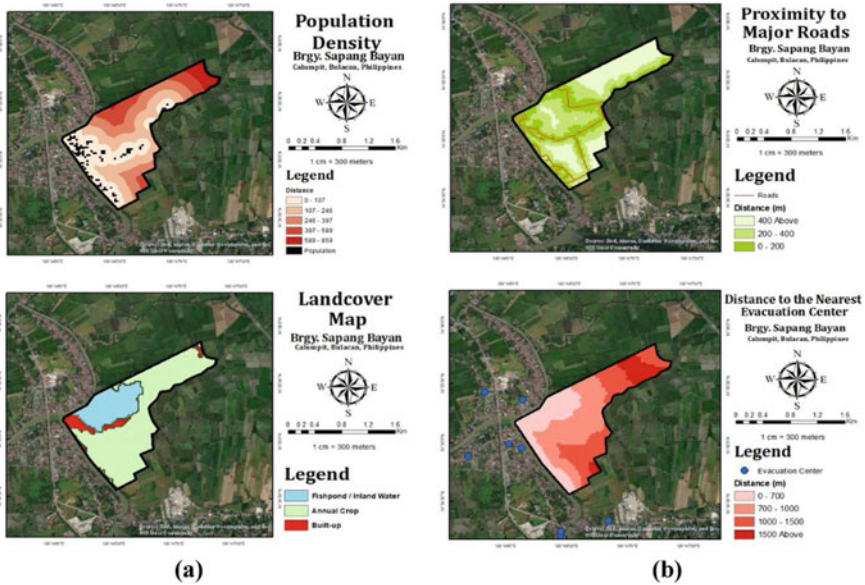
Fig. 4 Maps of study area considering flood hazard parameters **a** population density and land cover map, **b** proximity from major roads and distance to nearest evacuation center

3.3 Determination of Most Suitable Location for an Evacuation Center

Overall weights for the criteria were derived from normalized values of AHP. Based on Table 5, heavier weight was given to flood hazard parameters to ensure that the location that will be selected will not be susceptible to flood events having a weight of 55.7%. Following hazard parameters, the number of inhabitants and type of land cover was given second highest importance with a weight of 32% to consider not only the susceptibility of the study area, but also to minimize the risk of people that are residing in flood-prone areas of Sapang Bayan.

Output maps considering hazard parameters, exposure parameters and accessibility parameters were then combined and overlain in ArcGIS considering the weights that were derived from the AHP. Four classes (regions) were identified for the final

Table 5 Weight of criterion for suitability selection

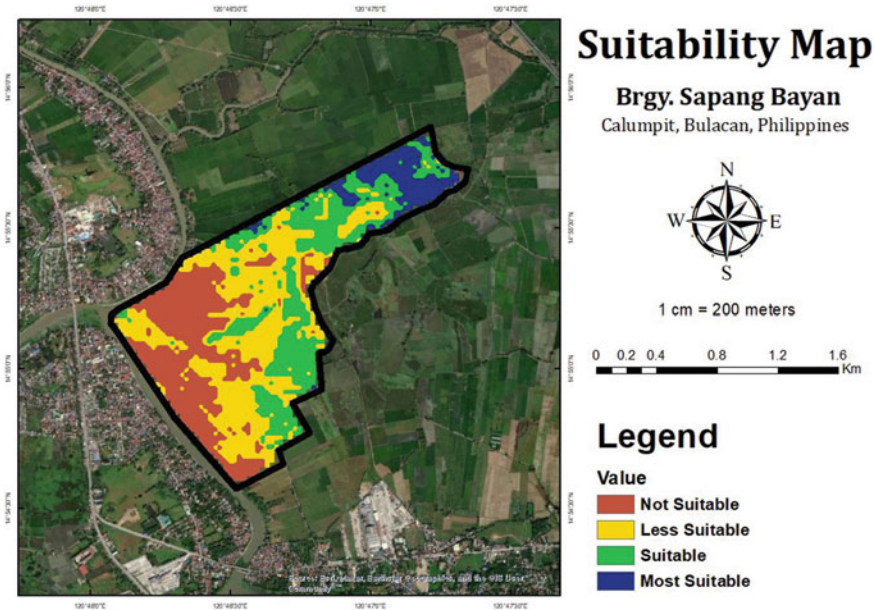|	Item description	Accessibility	Hazard	Exposure	Weight (%)
1	Accessibility	0.12	0.14	0.10	12.3
2	Hazard	0.50	0.57	0.60	55.7
3	Exposure	0.38	0.29	0.30	32.0

Fig. 5 Maps of study area considering flood hazard parameters **a** slope and elevation, **b** soil and flood map

map: most suitable, suitable, less suitable, and not suitable. Shown in Fig. 5 is the derived suitability map for the evacuation center.

Based on the suitability map output from GIS, it was found out that 8.98% of the total study area is highly suitable and can be recommended to be the location for the evacuation center. Majority of these areas can be found at the North-East side of the barangay where it is far from inundation that will come from the river as well as overland flow brought about by the topography. For areas that can be considered, 25.86% of the total study area can be said to be suitable enough to be the location of the evacuation center. Although majority of these suitable locations can be seen at the central part of the area, probably the consideration for accessibility of roads to be used in transporting evacuees are also seen to be interconnected in this region. In total, 65.14% of the total study area is at high risk of flooding being located near the riverbanks therefore getting a less to not suitable rating from the layered maps.

4 Conclusion

This paper explored the capability of GIS and multi-criteria decision analysis to determine the most suitable locations for an evacuation center of a flood-prone barangay, Sapang Bayan, in Calumpit Bulacan, Philippines.

Multiple Criteria Decision Analysis (MCDA) using Analytic Hierarchy Process (AHP) was used to combine spatial information with value judgements in choosing the most suitable location of an evacuation center in the area. A combination of Flood Hazard Parameters, Flood Exposure Parameters, and Accessibility Parameters were evaluated by assigning importance based on the assessment of proponents. Highest overall importance was given to Flood Exposure Parameters where it received a weight of 55.7% ensuring that priority in choosing the location was its safety from flooding. Second priority was given to exposure considering the population this is at risk to flooding in the area. With these importance ratings, the different layers were overlain to produce the final suitability map.

Results of the study identified that there is an 8.98% area of Sapang Bayan that was most suitable for an evacuation center that is safe from flooding. These are the areas that are far north-east of the study site due to its distance from the riverbank and its topographic characteristics. In addition, the central part of Sapang Bayan can be considered as location for an evacuation center since it was determined to be part of the 25.86% suitable area while the rest of the barangay (65.14%) was found to be least suitable to non-suitable for an evacuation center.

With the use of modern tools such as GIS and criteria-based methodology such as AHP, findings could help in the disaster preparedness of the barangay and the methodology of this study could also be applied to other flood-prone municipalities in their future urban planning.

References

1. Hussain M et al (2020) A comprehensive review of climate change impacts, adaptation, and mitigation on environmental and natural calamities in Pakistan. Environ Monitor Assess 192(1). https://doi.org/10.1007/s10661-019-7956-4
2. Pelling M et al (2004) Reducing disaster risk: a challenge for development
3. Khan H, Vasilescu LG, Khan A (2008) Disaster management cycle-a theoretical approach. J Manage Market 6(1):43–50
4. Jaisankar I, Velmurugan A, Swarnam TP (2018) Bioshield: an answer to climate change impact and natural calamities? In: Biodiversity and climate change adaptation in tropical Islands, Elsevier, pp 667–698. https://doi.org/10.1016/B978-0-12-813064-3.00024-7
5. Asio JMR (2020) Natural calamity, its impact and level of preparations: significance and implications to the community. [Online]. Available: https://ssrn.com/abstract=3718496
6. Edmonds DA, Caldwell RL, Brondizio ES, Siani SMO (2020) Coastal flooding will disproportionately impact people on river deltas. Nat Commun 11(1). https://doi.org/10.1038/s41467-020-18531-4

7. Hu M, Zhang X, Li Y, Yang H, Tanaka K (2019) Flood mitigation performance of low impact development technologies under different storms for retrofitting an urbanized area. J Clean Prod 222:373–380. https://doi.org/10.1016/j.jclepro.2019.03.044

8. Cvetkovic VM, Martinović J (2020) Innovative solutions for flood risk management. Int J Disaster Risk Manage 2(2):71–99. https://doi.org/10.18485/ijdrm.2020.2.2.5

9. Fontes de Meira L, Bello O (2020) The use of technology and innovative approaches in disaster and risk management: a characterization of Caribbean countries' experiences

10. Rathore V (2016) Technology in disaster management and disaster risk reduction: a review of applications. Technology (Singap World Sci) 6(4)

11. Madhloom HM, Al-Ansari N (2018) Geographical information system and remote sensing for water resources management case study: the Diyala River. Int J Civil Eng Technol (IJCIET) 9:971–984

12. Chang K (2016) Geographic information system. International Encyclopedia of Geography: People, the Earth, Environment and Technology: People, the Earth, Environment and Technology, pp 1–9

13. Wang Y, Li Z, Tang Z, Zeng G (2011) A GIS-based spatial multi-criteria approach for flood risk assessment in the Dongting Lake Region, Hunan, Central China. Water Resour Manage 25(13):3465–3484. https://doi.org/10.1007/s11269-011-9866-2

14. Hu S, Cheng X, Zhou D, Zhang H (2017) GIS-based flood risk assessment in suburban areas: a case study of the Fangshan District, Beijing. Nat Hazards 87(3):1525–1543. https://doi.org/10.1007/s11069-017-2828-0

15. Kabenge M, Elaru J, Wang H, Li F (2017) Characterizing flood hazard risk in data-scarce areas, using a remote sensing and GIS-based flood hazard index. Nat Hazards 89(3):1369–1387. https://doi.org/10.1007/s11069-017-3024-y

16. Ullah K, Zhang J (2020) GIS-based flood hazard mapping using relative frequency ratio method: a case study of Panjkora river basin, eastern Hindu Kush, Pakistan. PLoS One 15(3). https://doi.org/10.1371/journal.pone.0229153

17. Lyu HM, Sun WJ, Shen SL, Arulrajah A (2018) Flood risk assessment in metro systems of mega-cities using a GIS-based modeling approach. Sci Total Environ 626:1012–1025. https://doi.org/10.1016/j.scitotenv.2018.01.138

18. Danumah JH et al (2016) Flood risk assessment and mapping in Abidjan district using multi-criteria analysis (AHP) model and geoinformation techniques, (cote d'ivoire). Geoenviron Disast 3(1). https://doi.org/10.1186/s40677-016-0044-y

19. Boroushaki S, Malczewski J (2010) Using the fuzzy majority approach for GIS-based multicriteria group decision-making. Comput Geosci 36(3):302–312. https://doi.org/10.1016/j.cageo.2009.05.011

20. Greene R, Devillers R, Luther JE, Eddy BG (2011) GIS-based multiple-criteria decision analysis. Geogr Compass 5(6):412–432. https://doi.org/10.1111/j.1749-8198.2011.00431.x

21. Yao Y, Zhang Y, Yao T, Wong K, Tsou JY, Zhang Y (2021) A GIS-based system for spatial-temporal availability evaluation of the open spaces used as emergency shelters: the case of Victoria, British Columbia, Canada. ISPRS Int J Geoinf 10(2). https://doi.org/10.3390/ijgi10020063

22. Ouma YO, Tateishi R (2014) Urban flood vulnerability and risk mapping using integrated multi-parametric AHP and GIS: methodological overview and case study assessment. Water (Switzerland) 6(6):1515–1545. https://doi.org/10.3390/w6061515

23. Antronisamy TK, Din NM, Omar RC, Mustafa IS (2020) Analytical hierarchy process and power method for flood evacuation route selection

24. Gacu JG, Monjardin CEF, Senoro DB, Tan FJ (2022) Flood risk assessment using GIS-based analytical hierarchy process in the municipality of Odiongan, Romblon, Philippines. Appl Sci (Switzerland) 12(19). https://doi.org/10.3390/app12199456

25. Ali SA, Khatun R, Ahmad A, Ahmad SN (2019) Application of GIS-based analytic hierarchy process and frequency ratio model to flood vulnerable mapping and risk area estimation at Sundarban region, India. Model Earth Syst Environ 5(3):1083–1102. https://doi.org/10.1007/s40808-019-00593-z

26. Junian J, Azizifar V (2018) The evaluation of temporary shelter areas locations using geographic information system and analytic hierarchy process. Civ Eng J 4(7):1678. https://doi.org/10.28991/cej-03091104

27. Şentürk E, Erener A (2017) Determination of temporary shelter areas in natural disasters by GIS a case study for GÖLCÜK/TURKEY. Int J Eng Geosci 2(3):84–90. https://doi.org/10.26833/ijeg.317314

28. Ajim Ali S, Ahmad A (2018) Using analytic hierarchy process with GIS for Dengue risk mapping in Kolkata Municipal Corporation, West Bengal, India. Spatial Inf Res 26(4):449–469. https://doi.org/10.1007/s41324-018-0187-x

29. Güler D, Yomralıoğlu T (2017) Alternative suitable landfill site selection using analytic hierarchy process and geographic information systems: a case study in Istanbul. Environ Earth Sci 76(20). https://doi.org/10.1007/s12665-017-7039-1

30. Sapang Bayan, Calumpit, Bulacan Profile—PhilAtlas. https://www.philatlas.com/luzon/r03/bulacan/calumpit/sapang-bayan.html (accessed 11 Jun 2022)

31. Velez F (2020) 45,000 families in Bulacan affected by flood reaching 8 ft—Manila Bulletin. https://mb.com.ph/2020/11/16/45000-families-in-bulacan-affected-by-flood-reaching-8-ft/?fbclid=IwAR3Cj5VdUsD7M8ZOkIl4C6S6Z6pn2tkZMx7o9XEy5TTX9ji45c6YMl9Hs_I (accessed 08 Jun 2022)

32. Erkan TE, Elsharida WM (2020) Combining AHP and ROC with GIS for airport site selection: a case study in Libya. ISPRS Int J Geoinf 9(5). https://doi.org/10.3390/ijgi9050312

33. Rahmat ZG et al (2017) Landfill site selection using GIS and AHP: a case study: Behbahan, Iran. KSCE J Civ Eng 21(1). https://doi.org/10.1007/s12205-016-0296-9

34. Boyacı AÇ, Şişman A (2022) Pandemic hospital site selection: a GIS-based MCDM approach employing Pythagorean fuzzy sets. Environ Sci Poll Res 29(2). https://doi.org/10.1007/s11356-021-15703-7

35. Pasalari H, Nodehi RN, Mahvi AH, Yaghmaeian K, Charrahi Z (2019) Landfill site selection using a hybrid system of AHP-Fuzzy in GIS environment: a case study in Shiraz city, Iran. MethodsX 6. https://doi.org/10.1016/j.mex.2019.06.009

36. Tripathi AK, Agrawal S, Gupta RD (2022) Comparison of GIS-based AHP and fuzzy AHP methods for hospital site selection: a case study for Prayagraj City, India. GeoJournal 87(5). https://doi.org/10.1007/s10708-021-10445-y

37. Alkaradaghi K, Ali SS, Al-Ansari N, Laue J, Chabuk A (2019) Landfill site selection using MCDM methods and GIS in the Sulaimaniyah Governorate, Iraq. Sustainability (Switzerland) 11(17). https://doi.org/10.3390/su11174530

38. Yousefi H, Hafeznia H, Yousefi-Sahzabi A (2018) Spatial site selection for solar power plants using a gis-based boolean-fuzzy logic model: a case study of Markazi Province, Iran. Energies (Basel) 11(7). https://doi.org/10.3390/en11071648

39. Bandira PNA, Mahamud MA, Samat N, Tan ML, Chan NW (2021) GIS-based multi-criteria evaluation for potential inland aquaculture site selection in the george town conurbation, Malaysia. Land (Basel) 10(11). https://doi.org/10.3390/land10111174

40. Barzehkar M, Dinan NM, Mazaheri S, Tayebi RM, Brodie GI (2019) Landfill site selection using GIS-based multi-criteria evaluation (case study: SaharKhiz Region located in Gilan Province in Iran). SN Appl Sci 1(9). https://doi.org/10.1007/s42452-019-1109-9

41. Diamond J, Shanley T (1998) Infiltration rate assessment of some major soils end of project report ARMIS 4102 Author