

GIS-BASED FUZZY MULTI-CRITERIA DECISION MAKING METHODS: A SYSTEMATIC REVIEW AND META-ANALYSIS

PAUL AAZAGREYIR¹, PETER APPIAHENE², OBED APPIAH³, SAMUEL BOATENG⁴

¹ University of Professional Studies, Accra, Department of Information Technology Studies

^{2 3 4} University of Energy and Natural Resources-Sunyani, Department of Computer Science and Informatics-Ghana

E-mail: ¹paul.aazagreyir@upsamail.edu.gh, ²peter.appiahene@uenr.edu.gh, ³obed.appiah@uenr.edu.gh, ⁴samuel.boateng@uenr.edu.gh

ABSTRACT

Every activity must begin or conclude with a choice since decision making has become an essential element of daily life in this world. As a result, the number of contemporary decisions that require numerous considerations to be considered has skyrocketed. On the other hand, because humans are involved in the decision-making process, the multi-criteria decision-making process is burdened with incompleteness, subjectivity, ambiguity, and other fuzziness qualities. As a solution, numerous studies combined Fuzzy Set Theory with Multi-Criteria Decision Making Methods to provide effective and efficient judgments while reducing the aforementioned challenges. Regardless, geographical data-required decision making has been one of the key issues confronting the decision-making arena since the advent of multi-criteria decision making, demanding the usage of Geographic Information Systems. The current study attempted to conduct a systematic and critical assessment of around forty-nine (49) prior studies reported in academic publications on GIS-based Fuzzy Multi-Criteria Decision Making Methods throughout an eleven-year period (2011–2021). The following themes were specifically addressed: (i) the issue domains addressed, (ii) the research sites based on continents, (iii) the GIS-based Fuzzy Multi-Criteria Decision Making Methods employed and most generally used, and (iv) Sensitivity analysis. The findings indicated that the bulk of the research (30.61 percent) addressed the location analysis issue domain out of the 49 primary papers collected for the evaluation, while the risk assessment problem domain included the fewest studies (16.32 percent). Asia had the largest number of studies (46.93 percent), while Africa had the lowest number of publications (14.28 percent). Among the 18 primary GIS-Based Fuzzy Multi-Criteria Decision Making Methods employed, FAHP + GIS was found to be the most commonly used Fuzzy Multi-Criteria Decision Making Methods and Geographic Information Systems approaches. The study also indicated that just 17 studies (35% of the total) completed sensitivity analysis, whereas 32 studies (65% of the total) did not. Finally, we summarize the challenges and future research prospects for GIS-based Fuzzy Multi-Criteria Decision Making Methods.

Keywords: *Fuzzy, MCDM, Geographic Information Systems, FAHP, Sensitivity Analysis.*

1. INTRODUCTION

Geographic Information System (GIS)-based Fuzzy Multi-Criteria Decision Making Methods (FMCDMMs) has been applied in several research areas. Location Analysis, Environmental Modeling, Suitability Analysis, and Risk Assessment are some application areas, GIS-based FMCDMMs is best suited for selecting the utmost favored alternates from a pool of alternatives, particularly when the evaluation factors (criteria) are many often involving spatial data usage. As a result, FMCDMMs and GIS are a good pair of tools for rectifying location analysis(site selection) problems[1],[2]),environmental modelling

problems[3]–[8], suitability analysis problems[9]–[14], and finally risk assessment problems[15]–[19]. Location analysis involves studies that select sites for mounting an object based on certain factors or criteria. For instance, [20] established a feasible model for PV charging station (PVCS) site decision making that integrates geographic information system (GIS) and multi-criteria decision making (MCDM) approaches. A fast-growing trend is expected in the combination of fuzzy set theory with Multi-Criteria Decision Making Methods and Geographic Information Systems to handle problems related to the four research areas stated.

Fuzzy Multi-Criteria Decision Making Methods (FMCDMMs) is a strategy that seeks to eliminate ambiguity in decision making while producing more precise outcomes[20], [21]. This newcomer strategy enables decision makers to express their opinions using linguistics terms. FMCDMMs studies, for example, abound. [23] Studied equipment selection using fuzzy TOPSIS and fuzzy VIKOR. [24] Presented a hybrid model of fuzzy multi-criteria decision making for the selection of cans supplier/ suppliers at Nutridar Factory in Amman-Jordan. Other fuzzy multi-criteria decision making methods include[22], [23]. A geographic information system (GIS) is a type of information system that deals with data that has spatial or geographic coordinates. In other words, a GIS is both a database system [27] containing spatially related data and a collection of data-processing techniques. GIS are tools for storing, organizing, analyzing, and presenting geographically referenced data (i.e. Raster (Image) and Vector (Shape file)), and they may help with planning and decision making in a range of scenarios where georeferenced information is important. Researchers have begun combining the three concepts i.e. Fuzzy set, Multi-Criteria Decision Making Methods and Geographic Information Systems to address pressing problems in different areas.

The growing trend in the integrated three concepts usage saw a sharp increase from 2017 to 2020. This is discovered from extant literature and reported in the result section of this paper. Extant studies that explored Fuzzy Multi-Criteria Decision Making Methods and Geographic Information Systems include; [4]–[6], [24]–[30], however, all the above were primary studies. Also, there were few secondary or survey extant studies similar to the present paper[20], [31]–[37]. A thorough assessment of research publications that use multi-criteria decision-making models for urban travelers was presented [29]. Also [30] offered an assessment of the literature on the use of MCDM approaches in the field of sustainable engineering. [29] and [30] Review studies considered only Multi-Criteria Decision Making Methods in Urban Passenger engineering transport systems and sustainability engineering respectively. Also, [36] presented the following research questions: which evaluation criteria were employed for each site selection issue domain? , and which MCDM approaches were often used in a certain site selection issue domain?. [32] presented a fresh evaluation that differed from previous reviews by concentrating on three areas: issue from MCDM

viewpoints, as well as GIS tools. They classify the applicable methodologies, decision criteria, MCDM environment, and kind of criteria after thoroughly studying the paper.[36], and [32] undertook review studies on site selection problems. While,[36], explored MCDM Methods,[32] did not. Furthermore,[34] presented a review of fuzzy application in agriculture has shown promising results.[34] did not consider Multi-Criteria Decision Making Methods and Geographic Information Systems along-side the fuzzy. Finally, [38] provided answers to the following research questions. In energy policy and decision making, what fuzzy MCDM approaches have been employed?. What are the energy use areas? What role does energy play in terms of sustainability? Which criteria are taken into account in energy decision-making problems? [20] in their review study considered fuzzy Multi-Criteria Decision Making Methodologies for energy policy making. [20] study was the closest to the present study but, they did not consider geographic information systems in their study. Also, their studies focus falls outside the domains under consideration in the current study.[37] review study focused on MCDA approaches, disposal methods, and solid waste types, and countries.[37] studied considered Geographic Information Systems and Multi-Criteria Decision Making Methods but did not consider fuzzy along side with them.

Despite all these review studies[20], [31]–[37]. A comprehensive systematic review of Fuzzy Multi-Criteria Decision Making Methods and Geographic Information Systems that takes into account all possible factors, such as the problem domains that considered Fuzzy Multi-Criteria Decision Making Methods and Geographic Information Systems, the study settings, the frequency with which the fuzzy Multi-Criteria Decision Making Methods and Geographic Information Systems combination was used, and whether sensitive analysis was performed or not, is required. As a result, to address the void, this work offers a comprehensive systematic evaluation of current literature based on FMCDMMs and GIS. The current review is classified according to the problem domains (Location Analysis, Suitability Analysis, Environmental Modelling, and Risk Assessment), the study location (Africa, Asia, Europe and America), and Sensitivity analysis (Sensitivity Analysis Performed and No Sensitivity Analysis Performed). When compared to other recommendations, the Preferred-Reporting Items for Systematic-Review and Meta-

Analysis (PRISMA) flow diagram was chosen for this study because of its capacity to increase the value and quality of the systematic review ([39]–[41]). This study was motivated by the fact that geographical data-required decision making couple with fuzziness qualities has been one of the key issues confronting the decision-making arena lately demanding the usage of Geographic Information Systems and Fuzzy Multi-Criteria Decision Making Techniques particularly in problem areas such as; Location Analysis, Suitability Analysis, Risk Analysis and Environmental Modelling. The current study contributes to knowledge as follows:

1. A well-organized review of relevant literature with an emphasis on the various problem domains that used Fuzzy Multi-Criteria Decision Making Methods and Geographic Information Systems, which also happens to be the first Systematic Literature Review and Meta-Analysis study on FMCDMMs and GIS to date.
2. Recognition of distinct authors based on continents and the journals from which many of the original research were derived based on the stringent inclusion and exclusion criteria.
3. A thorough and exhaustive evaluation of 49 prior state-of-the-art research on FMCDMMs and GIS-based on the mix of methodologies utilized and frequently used approaches, as well as whether or not sensitivity analysis was undertaken.
4. Established arguments for future research directions based on literature results and propose solutions to pique researchers' interest in enhanced research production utilizing FMCDMMs and GIS techniques.

The review's research approach is outlined in Section 2. Section 3 contains an analysis and reporting of the papers evaluated along with discussion, Section 4 discusses the conclusion and future directions.

Table 1: Abbreviations and Full Meanings of Fuzzy Multi-Criteria Decision Making Methods and Geographic Information Systems

No	Abbreviation	Full Meaning
1	FAHP	Fuzzy Analytic Hierarchy Process
2	FOWA	Fuzzy Ordered weighted Averaging
3	GIS	Geographic Information Systems
4	FSAW	Fuzzy Simple Additive Weighting
5	FTOPSIS	Fuzzy Technique For Order Preference By Similarities To Ideal Solution
6	FDEMATEL	Fuzzy Decision Making Trial And Evaluation Laboratory
7	WBM	Worst Best Method
8	FANP	Fuzzy Analytic Network Process
9	FLOWA	Fuzzy Linguistic Ordered Weighted Average
10	FMULTI MOORA	Fuzzy Multiobjective Optimization by Ratio Analysis plus
11	FELECTRE	Fuzzy Elimination Et Choix Traduisant la Realite
12	FBWM	Fuzzy Best Worst Method
13	IVFRN	Interval Valued Fuzzy Rough Numbered
14	AHP	Analytical Hierarchy Process
15	FVIKOR	Fuzzy Vlekriterijumsko KOMPromisno Rangiranje
16	FTODIM	Fuzzy Interactive Multi-criteria Decision Making

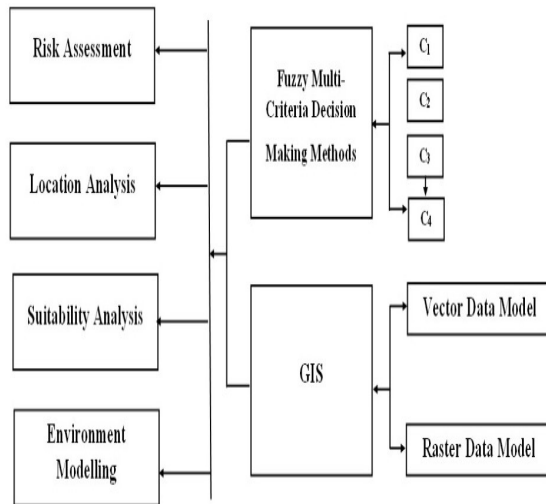


Fig 1: A Framework Showing How GIS-Based Fuzzy MCDMS Can Be Combined.

From Fig.1, C1, C2, C3 and C4 represent Criteria and alternatives that the Fuzzy Multi-Criteria Decision Making Methods can take as inputs. Also, Vector data and Raster Data models are the most common data models in GIS data. It shows that the GIS platform will take either vector data such as; (lines like roads, points like X, Y coordinates of Fuel station location or Polygon like a big build) Or Raster data like vegetation, and satellite images as inputs depending on the problem. The other side of the diagram shows the problem domains of focus in this study such as; Risk Assessment, Location Analysis, Suitability Analysis and Environmental Modelling/Studies.

2. METHODOLOGY

The current study undertakes a thorough analysis of the literature on Fuzzy Multi-Criteria Decision Making Methods and Geographic Information Systems.

2.1 Data collection

A total of forty-nine (49) state-of-the-art research works published by Elsevier Journals (See Table 2) indexed in ScienceDirect electronic database and are relevant to the scope of the current study were downloaded from the internet, using the search, “Geographic Information System” AND (Fuzzy MCDM OR Fuzzy MCDA or “multi-criteria” OR MADM OR Fuzzy AHP OR fuzzy TOPSIS OR fuzzy VIKOR OR Fuzzy DEAMATEL OR Fuzzy ELECTRE). Each piece of downloaded material was then thoroughly

examined and classified into the four problem categories of location analysis, suitability analysis, environmental modeling, and risk assessment.

Table 2: Name of Journal and Number of Papers Downloaded from Journals

Name of Journal	Number of Papers
Saudi Journal of Biological Sciences	1
Applied Geography	1
Heliyon	1
Applied Energy	2
Applied Geochemistry	1
Biomass and Bioenergy	1
Computers & Industrial Engineering	1
Energy	1
Geoscience Frontiers	1
Hydro Research	1
International Journal of Disaster Risk Reduction	2
Information Processing in Agriculture	1
Journal of Cleaner Production	4
Journal of Hydrology	2
Physics and Chemistry of the Earth	1
Sustainable Cities and Society	2
Tourism Management Perspectives	1
Sustainable Energy Technologies and Assessments	1
Environmental and Sustainability Indicators	1
Ecological Indicators	2
Solar Energy	1
Renewable Energy	1
Environmental Modelling & Software	1
Journal for Nature Conservation	1
Computers & Geosciences	1
Journal of Applied Geophysics	1
City and Environment Interactions	1
Habitat International	1
Groundwater for Sustainable Development	1
Journal of Environmental Management	2

Socio-Economic Planning Sciences	1
Ecological Modelling	1
Renewable and Sustainable Energy Reviews	2
Science of the Total Environment	1
Food and Chemical Toxicology	1
Land Use Policy	2
Computers and Electronics in Agriculture	1
Energy Conversion and Management	1
Total	49

2.2 The study framework

The protocol, which outlines the reason, hypothesis, and planned techniques of investigation, determines the quality of every systematic review. [41]. Nonetheless, many systematic Literature Review studies do not properly disclose their framework in a graphical style for simple comprehension by the research community in order to facilitate technique replication. A systematic review framework that is clear and well-described enhances comprehension and assessment of the approaches utilized. The PRISMA model [40] was utilized in this study from then on. (Fig. 2). As shown in Fig. 2, PRISMA depicts the flow of information from one stage of a systematic review of the literature, including the total number of studies identified, excluded, and included, as well as the reasons for inclusion and exclusion. As depicted in Fig. 2, The PRISMA flow diagram consisted of five (5) phases. The first phase entails specifying the scope of the review, developing questions, and adding or omitting things. Phase 2 involves scouring the literature for relevant research using keywords. Phase 3 is assessing whether or not an article should be included by examining its abstracts to see whether it fits inclusion requirements. While step 4 covers the characterization of the papers for keyword mapping. This study intended to provide a summary of research in four areas: location analysis, suitability analysis, environmental modeling, and risk assessments, in order to pave the way for future investigations. As a result, the fifth (5) stage provides a thorough quantitative synthesis (meta-analysis) of the research included in the review. Our literature search yielded three thousand five hundred and ninety-six (3596) publications, all from the ScienceDirect database.

(See Table 2). Six hundred and six (606) duplicates were deleted from the 2990 records, leaving two thousand nine hundred and ninety (2990) records shortlisted for the screening step. Two thousand eight hundred and eighty-five (2885) records were removed during the screening stage, including studies that were not related to Fuzzy Multi-Criteria Decision Making Methods and Geographic Information Systems, as well as those whose primary publication language was not English and review papers. We left one hundred and five (105) records, and of the 105 records, we eliminated fifty-six (56) more for different reasons. (See fig. 2) This lowered the number of publications eligible for analysis to 49. For the qualitative analysis, 49 publications were selected. As a result of excluding zero (0) records from the qualitative analysis, all 49 records were used for the quantitative analysis. (Refer to Figure 2).

3. FINDING AND DISCUSSION

The evaluated literature was divided into four categories: issue domains, research site, GIS-based FMCDMMs employed, and sensitivity analysis. The findings of this research is novel because this is the first ever study to conduct a systematic literature review on a subject of GIS-Based Fuzzy Multi-Criteria Decision Makings. (Refer to Table 3).

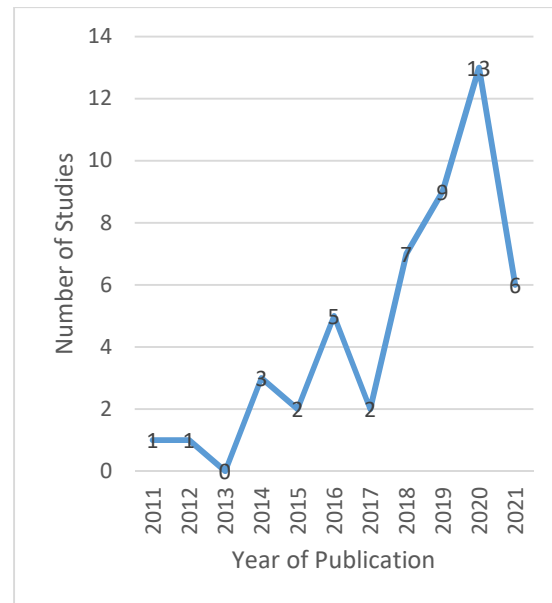


Fig 3: A Graph Showing the Trend in Years of Fuzzy Multi-Criteria Decision Making Methods and Geographic Information Systems (Source: Author's Construct)

Figure 3 from 2011 to 2021, displays the trend in the number of articles published on Fuzzy Multi-Criteria Decision Making Methods and Geographic Information Systems. The findings indicated a non-linear trend in the number of research published throughout the period. Most research in the field was published in 2020, while the fewest were published between 2013, 2012, and 2011. The findings support the observation in [39] that the trend of the number of publications versus the year of publication is not linear. It is worth mentioning that 28.57 percent of the total number of articles published in these 11 years were published between 2011 and 2017, while 71.42 percent were published in the last four years (between 2018 and 2021). More publications were noticed throughout this four-year era in 2020, with a shockingly low amount of publishing in 2021, maybe due to the effect of covid-19.

Problems Domains

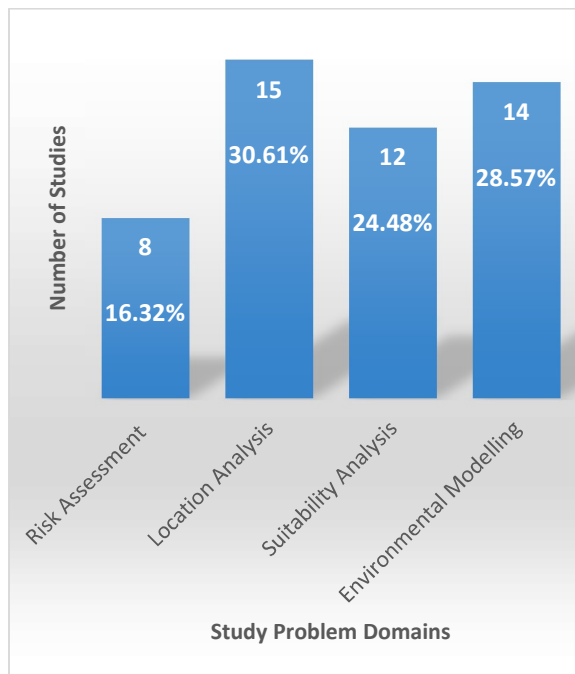


Fig 4: Showing Number of Publications Against Problem Domains

Figure 4 depicts the results of a literature review on GIS-based FMCDMMs based on issue domains. The analysis discovered that the majority (30.61 percent) of the studies addressed the Location Analysis issue domain, followed by the Environmental Modelling problem domain 28.57 percent. Whereas 12 of the research (24.48 percent) handled the Suitability Analysis issue domain, 8 studies (16.32 percent) addressed the

Risk Assessment problem domain. This clearly shows that there is a significant void in the research on GIS-based FMCDMMs that handle the risk assessment problem area. Despite the fact that location analysis has the most publications addressing that issue domain, there is a large gap in the literature in that respect in the Ghanaian context since no article from Ghana addressed the location analysis problem area. Our findings on environment studies/modeling articles contradict the conclusions of [35][31] findings reflect our findings that the environmental studies/modeling field came in second, with 14 publications accounting for 28.57 percent of the 49 primary studies obtained for the review. Among the sample studies used to solve location analysis/site selection issues are [25], [27], [30], [42]–[47]. Furthermore, example of environmental studies/modeling include [5], [24], [48]–[50]. Papers on suitability analysis include [5], [12], [26]. Finally, research that addressed risk assessment issues include the following: [16], [18], [51]. This finding is unique because it is the first ever systematic review study to find that risk assessment is the least studied problem areas in the GIS-Based

Fuzzy Multi-Criteria Decision Making methods studies.

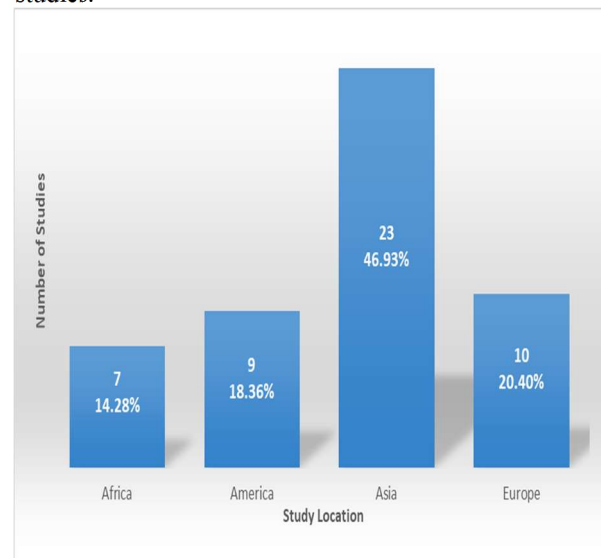


Fig 5: Showing Number of Publications And Study Locations Based on Continent

Study origin

Figure 5 depicts the studies and their sources (continents). The origins of the surveyed studies were investigated in order to determine the relationship between the GIS-based FMCDMMs

and the continents where they were published. In terms of geographical coverage, it was discovered that the majority of research (46.93 percent) was conducted in Asia, 20.40 percent in Europe, 18.36 percent in America, and 14.28 percent in Africa. This clearly shows that there is a significant vacuum in the literature on the GIS-Based Fuzzy Multi-Criteria Decision Making Method in Africa. In particular, among the 49 research evaluated for the review, just one came from Ghana, accounting for 2.04 percent of all publications. As a result, there is a need for more study employing GIS-based FMCDMMs from the African continent, including Ghana. Our discovery that Africa has the fewest articles backs up the findings of [39]. [39], on the other hand, focused on the impact of information technology on productivity. Our findings are similarly consistent with those of [40]. However, [40] study focused on electrical load forecasting, with North America having the fewest publications rather than Africa.

(Refer to Figure 6) Figure 6 clearly shows the numerous combinations of Fuzzy Multi-Criteria Decision Making Methods with Geographic Information Systems. The Literature yielded a total of 18 Major FMCDMMs and Geographic Information Systems combinations. As shown in Figure 6, FAHP+ GIS was the most commonly employed FMCDMMs and GIS technique among the 49 primary studies analyzed from 2011 to 2021. Our research is comparable to [52], [52] discovered Fuzzy AHP to be the most extensively utilized Fuzzy Multi-Criteria Decision Making Methods in a review study. Their work is comparable to ours in that, it is the first comprehensive literature review of GIS-based FMCDMMs. Surprisingly, FAHP+GIS was used in 17 papers published during a 7-year period, out of the 11-year period analyzed in this systematic review. (See Fix 6). Second, FAHP+FTOPSIS + GIS was investigated in seven research published over a five-year period. FDEMATEL + GIS has also been published in six research over four years. Surprisingly, the bulk of the GIS-based FMCDMMs was only used once in a single year. These include; FAHP+FSAW+FTOPSIS+GIS, FDEMATEL+FAHP+GIS, IT2FAHP+FTOPSIS+GIS, FDEMATEL+FTOPSIS+GIS, FMULTIMOORA +FBWM+GIS and FAHP+FVIKOR+GIS were explored in studies published in 2019. In 2020, FAHP+WBM+GIS, FAHP+FANP+GIS, IVFRN+AHP+GIS and FTODIM+GIS were utilized studies published. FAHP+GIS was explored in a study in 2014. Also, in 2012,

FAHP+FOWA+GIS was examined in a study published and finally, FLOWA+GIS was used in a study published in 2013. It is clear that 2019 recorded the highest studies that were utilized just once in one year. From Figure 6, just a few studies combine 4 or more GIS-based FMCDMMs in solving a problem. It is therefore, an open research gate for researchers to explore. Since, the majority of the GIS-based FMCDMMs combinations were explored just once, there is therefore, a need for more studies using some of those combinations. Finally, there are also other possible GIS-based FMCDMMs combinations that can be explored by researchers and more particularly Ghanaian' researchers.

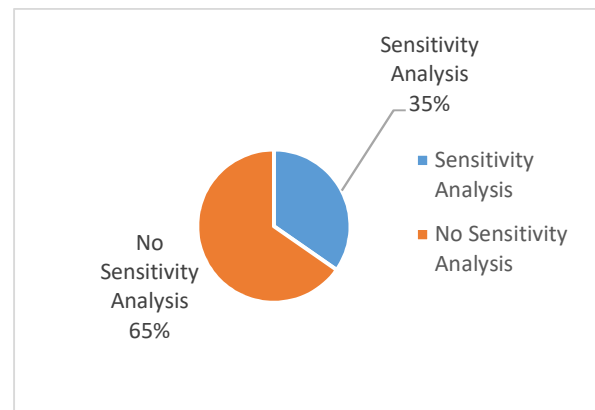


Fig7: A Chat Showing Studies With and Without Sensitivity Analysis

According to Evans, (1984) Sensitivity analysis is a mathematical study that analyzes how potential changes or errors in parameter values impact model findings. In an applied organizational setting, sensitivity analysis is defined as "a study to assess the responsiveness of an analysis's outcomes to changes or errors in parameter values used in the analysis.". The application of sensitivity analysis enhances the compatibility of results [26], [54]. According to figure 7, only 17 studies (35 percent of the main studies chosen for the quantitative synthesis (Meta-analysis)) completed sensitivity analysis, whereas 32 studies (65 percent of the studies) did not undertake sensitivity analysis. Our findings support the findings of [52] that found only 37 percent of research completed sensitivity analysis, while 63 percent of the primary studies assessed did not. This also revealed a significant gap, demanding more research into sensitivity analysis.

4. FUTURE RESEARCH DIRECTIONS

1. Several research (30.61 percent) used GIS-based Fuzzy Multi-Criteria Decision Making Methods to handle the Location Analysis issue domain, whereas 16.32 percent of GIS-based FMCDMMs studies addressed the Risk Assessment problem domain. Despite the fact that the location analysis issue domain had the most research, there was no study from Ghana that accounted for the high number. Only one of the 49 primary studies gathered for the study came from Ghana. The publication from Ghana addressed the issue domain of environmental studies/modeling. More research from Ghana is needed to address the location analysis issue domain. Clearly, further research is required to solve the risk assessment issue too. Hence, the study concludes that environmental studies/modelling and risk assessment problem domains require more study from African counties particularly Ghana.
2. In Africa, there has been limited research on GIS-based Fuzzy Multi-Criteria Decision Making Methods (7 out of 49). Despite the fact that the continent has great researchers in Artificial Intelligence, the continent's researchers show little interest in Fuzzy Multi-Criteria Decision Making Methods and related concepts research in most of its countries, particularly Ghana, resulting in the continent's low publications. Therefore, the paper suggests that additional research from African countries especially Ghana focusing on GIS-based Fuzzy Multi-Criteria Decision Making is highly recommended.
3. The Literature yielded a total of 18 Major FMCDMMs and Geographic Information Systems combinations. FAHP+ GIS was the most commonly employed FMCDMMs and GIS technique among the 49 primary research assessed between 2011 and 2021. FAHP+GIS was studied in 17 research published during a 7-year period, out of the 11-year period covered in this systematic review. The study concludes that because the majority of the GIS-based FMCDMMs combinations were only investigated once, there is the need for more research employing some of those combinations. Finally, there are additional conceivable GIS-based FMCDMMs combinations that scholars particularly Ghanaian researchers should consider exploring.

4. Only 17 studies (35 percent of the main studies chosen for the quantitative synthesis (Meta-analysis)) completed sensitivity analysis, whereas 32 studies (65 percent of the studies) did not. This also revealed a significant gap, demanding more research into sensitivity analysis. The study concludes requiring researchers to undertake more studies that complete sensitivity analysis in GIS-based Fuzzy Multi-Criteria Decision Making Methods. Since, that is one of the ways to ascertain the robustness of the study model under scenarios where more criteria are added or removed, what will be the effect on the initial ranking results prior to the scenarios.

5. Overall, the study suggests that the GIS-based FMCDMMs arena of research requires more innovation studies. The few primary studies of 49 considered for the meta-analysis is the weakness of this study. However, this is because the authors wanted to focus only on a particular academic database (i.e., ScienceDirect). Going forward, review papers on this subject matter can consider many academic databases such as; Scopus, IEEE Xplore, Springer Link, MDPI, IGI Global, Hindawi, among others. Doing so will increase the number of primary studies that will be considered for the Meta-Analysis (Quantitative Synthesis). Also, the further studies can focus on other themes either that the themes used in this study. Finally, further studies can also combine Machine Learning Techniques with GIS-based Fuzzy Multi-Criteria Decision Making Methods.

Limitation of the study

The few primary studies of 49 considered for the meta-analysis is the weakness of this study. However, this is because the authors wanted to focus only on a particular academic database (i.e ScienceDirect). Going forward, review papers on this subject matter can consider many academic databases such as; Scopus, IEEE Xplore, Springer Link, MDPI, IGI Global, Hindawi, among others. Doing so will increase the number of primary studies that will be considered for the Meta-Analysis (Quantitative Synthesis). Also, the further studies can focus on other themes either that the themes used in this study. Finally, further studies can also combine Machine Learning Techniques with GIS-based Fuzzy Multi-Criteria Decision Making Methods.

5. CONCLUSIONS

The purpose of this study was to examine current literature on GIS-based Fuzzy Multi-Criteria

Decision Making Methods and to suggest the potential for future research. From the findings, risk assessment recorded the least publications as compared to suitability analysis, environmental modelling and Locational Analysis. Africa witnessed the minimum number of studies as against America, Europe, and Asia. Furthermore, Fuzzy Analytic Hierarchic Process combined with Geographic Information System recorded the highest number of publications. Finally, majority of the studies did not perform sensitivity analysis to ascertain the resilience of the models used. However, these findings are based on only 49 primary papers from high impact journals from only scienceDirect database.

The paper adds to the body of knowledge in computer science on GIS-based Fuzzy Multi-Criteria Decision Making Methods. First, the paper provides the first Systematic Literature Review and Meta-analysis study on the subject of GIS-based Fuzzy Multi-Criteria Decision Making Methods with explicitly stated Systematic Literature Review research questions. Based on the findings, this paper suggests future research topics for academics interested in GIS-based Fuzzy Multi-Criteria Decision Making Methods.

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Table 3: A Cross-Section of the Reviewed Papers

	Ali, Sk Ajim; Parvin, Farhana; Vojteková, Jana; Costache, Romul...	GIS-based landslide susceptibility modeling: A comparison between fuzzy multi-criteria and machine learning algorithms	2021	Geoscience Frontiers
	Ildoromi, Ali Reza; Sepehri, Mehdi; Malekinezhad, Hossein; Kiani-Harch...	Application of multi-criteria decision making and GIS for check dam layout in the Ilanlu basin, northwest of Hamadan Province, Iran	2019	Physics and Chemistry of the Earth, Parts A/B/C
	Feizizadeh, Bakhtiar; Shadman Roodposhti, Majid; Jankowski, Piotr...	A GIS-based extended fuzzy multi-criteria evaluation for landslide susceptibility mapping	2014	Computers and Geosciences
	Mete Kilic, Orhan; Ersayin, Kemal; Gunal, Hikmet; Khalofah, Ahlam; Sa...	Combination of Fuzzy-AHP and GIS Techniques in Land Suitability Assessment for Wheat (<i>Triticum aestivum</i>) Cultivation	2021	Saudi Journal of Biological Sciences
	Rodríguez, Reynel; Gauthier-Maradei, Paola; Escalante, Humberto	Fuzzy spatial decision tool to rank suitable sites for allocation of bioenergy plants based on crop residue	2017	Biomass and Bioenergy
	Sánchez-Lozano, J M; García-Cascales, M S; Lamata, M T	Evaluation of suitable locations for the installation of solar thermoelectric power plants	2015	Computers & Industrial Engineering
	Das, Biswajit; Pal, Subodh Chandra	Combination of GIS and fuzzy-AHP for delineating groundwater recharge potential zones in the critical Goghat-II block of West Bengal, India	2019	HydroResearch
	Amini, Sherwin; Rohani, Abbas; Aghkhani, Mohammad Hossein; Ab...	Assessment of land suitability and agricultural production sustainability using a combined approach (Fuzzy-AHP-GIS): A case study of Mazandaran prov...	2020	Information Processing in Agriculture
	Noori, Abbas Mohammed; Pradhan, Biswajeet; Ajaj, Qayssar Mahmood	Dam site suitability assessment at the Greater Zab River in northern Iraq using remote sensing data and GIS	2019	Journal of Hydrology
	Doğan, Umut; Koçak Güngör, Merve; Bostancı, Bülent; Yılmaz Bakır, Neşe	GIS Based Urban Renewal Area Awareness and Expectation Analysis Using Fuzzy Modeling	2020	Sustainable Cities and Society
	Charabi, Yassine; Gastli, Adel	PV site suitability analysis using GIS-based spatial fuzzy multi-criteria evaluation	2011	Renewable Energy
	Khashei-Siuki, Abbas; keshavarz, Akbar; Sharifan, Hossein	Comparison of AHP and FAHP methods in determining suitable areas for drinking water harvesting in Birjand aquifer, Iran	2020	Groundwater for Sustainable Development
	Zhang, Jiuquan; Su, Yirong; Wu, Jinshui; Liang, Hongbo	GIS based land suitability assessment for tobacco production using AHP and fuzzy set in Shandong province of China	2015	Computers and Electronics in Agriculture
	Çetinkaya, Cihan; Özceylan, Eren; Erbaş, Mehmet; Kabak, Mehmet	GIS-based fuzzy MCDA approach for siting refugee camp: A case study for southeastern Turkey	2016	International Journal of Disaster Risk Reduction
	Lyu, Hai Min; Shen, Shui Long; Zhou, An Nan; Zhou, Wan Huan	Flood risk assessment of metro systems in a subsiding environment using the interval FAHP-FCA approach	2019	Sustainable Cities and Society

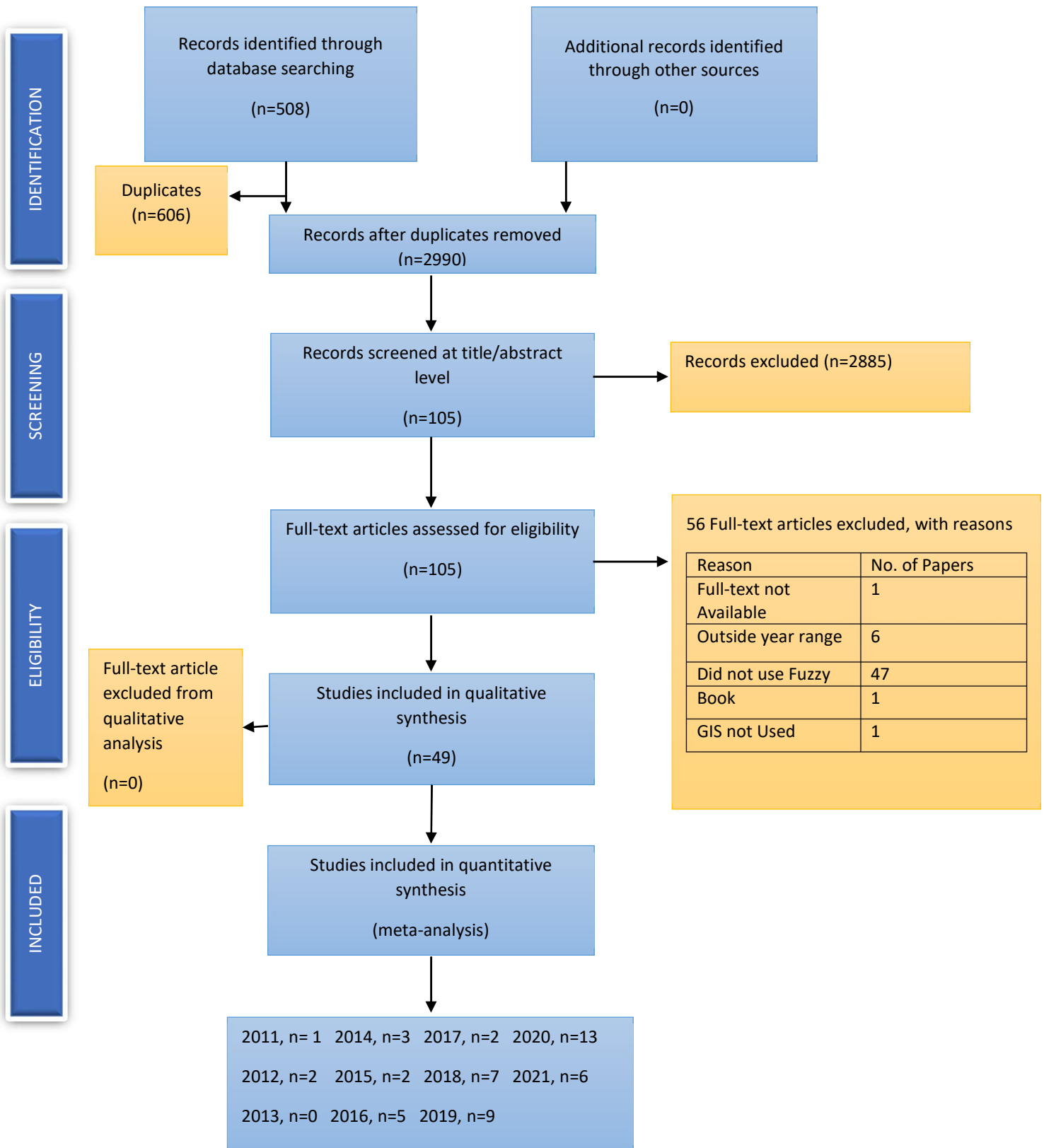


Fig 2: The Adopted PRISMA Flow Diagram. Source [40].

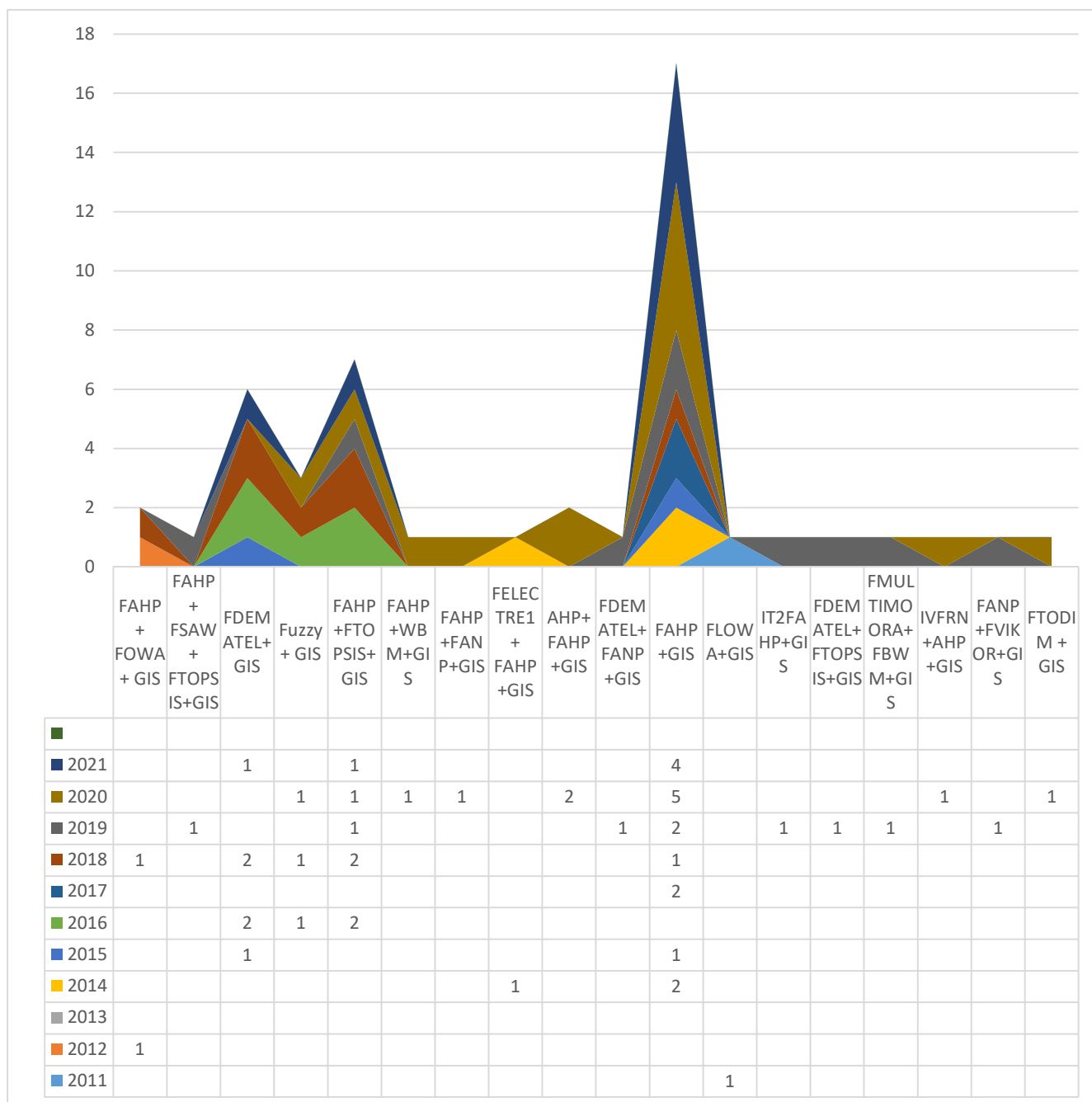


Fig 6: Showing Number of Studies And GIS-Based Fuzzy Multi-Criteria Decision Making Method Used