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Integration of Multi-Criteria Decision Model, Analytic Hierarchy Process and Geographic Information System for Landfill Site Selection: An Overview of Varanasi City

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Abstract

Effective solid waste management is essential in urban areas. Despite efforts by local authorities in Indian cities to handle waste through various methods, landfilling remains the most convenient disposal method. This study aims to identify the optimal site for scientific landfilling in Varanasi City using a multi-criteria decision-making model, Analytical Hierarchy Process (AHP), and Geographic Information System (GIS). Initially, a comprehensive literature review, the Municipal Solid Waste Management Rule of 2016, and expert opinions were used to determine site selection criteria. Eleven criteria, including proximity to rivers or lakes, groundwater table, settlement proximity, and slope etc., were identified as crucial for landfill suitability. Experts assigned an appropriateness score to each criterion, ranging from 1 to 5, where 5 represented the best rating and 1 the lowest. As the criteria are not equally significant, weights were assigned based on their importance in decision-making using AHP. Criteria maps were prepared using ArcGIS 10.6.1, and a final map was generated through weighted overlay assessments. The investigation identified Khutahna (0.43 km^2), Chhitauni (0.22 km^2), Kakarhia (0.09 km^2), and Kadi Chak (0.06 km^2) as high-suitability zones for landfilling; Mustafabad (0.21 km^2), Chandpur (0.15 km^2), and Jalhupur (0.13 km^2) as moderate-suitability zones; and the remaining section of the region as unsuitable. A site walkover is recommended to confirm the accuracy and suitability of the candidate locations.

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Analytic Hierarchy Process; Geographic Information System; Landfilling; Multi-Criteria Decision Making; Site Walkover.

Introduction

Evolution of human beings is undoubtedly one of the magnificent creations of mother nature, but unfortunately, the anthropogenic activities have wounded the environment. Solid waste generation is one of human activities that negatively impacts the environment in rural, urban and metropolitan areas, and improper handling of the trash has made the

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issue worse. Currently, a number of strategies are being employed to lessen the quantity of solid waste; nonetheless, increasing urbanisation, changing consumption patterns, and rapid population expansion are contributing to generate a large volume of solid waste. The handling of solid waste is performed through a variety of techniques, including composting, incineration, and landfilling.[1] In developing nations such as India, landfilling is the most prevalent method of managing solid waste.[2]

The rate of waste generation is increasing globally. It has been projected that the yearly production of waste will increase by 73% from 2020 levels (2.24 thousand million tonnes of solid trash/garbage or 0.79 kg/person/day) to 3.88 thousand million tonnes in 2050, generally because of rapid urbanization and growth in the number of people.[3] As garbage production increases, quantum of disposal of solid waste will also be increased. Therefore, even though landfilling is close to the bottom of the waste management hierarchy,[4] it may be engaged in more frequent manner to handle the waste. The process of disposing of waste in a landfill involves first spreading the rubbish into small cells, packing it down, and then burying it in a bed of soil.[5] Because of the social, environmental, technological, economic, and legal aspects involved, choosing an appropriate location for waste disposal is extremely complex and challenging. Owing to rapidly expanding industries and growing population, it becomes a crucial decision to locate the landfill site at appropriate place.[6,1,7] Environmental factors are the most significant elements discussed above since they have a direct impact on the environment, ecology, and public health.[8]

This study provides a helpful strategy for selecting disposal sites, before that it is critical to understand the condition of the existing waste treatment plants. First and foremost, it is imperative to recognise that the Ramna Waste to Charcoal Plant, Varanasi (UP) (earlier Ramna open dumping ground) and the Karsara Waste Treatment Plant, Varanasi (UP) were constructed at random. The selection criteria were not disclosed to the researcher; nonetheless, it is believed that the availability of land played a crucial role in the decision-making process than a comprehensive assessment and scientific evaluation and analysis.

Despite the fact that the Ramna Waste to Charcoal Plant and the Karsara Waste Treatment Plant (KWTP) are contracted to handle and process the waste materials of the study area, and the KWTP can currently handle up to 600 MT (full capacity) of waste per day, VMC is dealing with a number of problems, including improper handling and open dumping of waste around the plant, which results in air pollution, offensive odours, and the release of greenhouse gases i.e. methane. They are also having trouble finding buyers for manures made from the waste material. Furthermore, the garbage being that was brought in is not segregated, which means that it can include dangerous substances that seep into the ground and endanger water bodies.

In addition, waste is gathered unscientifically at the city's numerous transfer stations prior to being sent to the waste treatment facility, which fosters the growth of mosquitoes and other rodents and could worsen the spread of diseases i.e. malaria and dengue. Furthermore, improper disposal of waste materials degrades the aesthetic appeal of the city, and allowing animals unrestricted access to urban garbage may increase the risk of animal-to-human disease transmission.[9-12]

Establishing a scientific landfill site in the north of the research area is of utmost importance, as the KWTP cannot handle the entire waste. This measure is required to dispose of garbage in a proper and scientific manner, as well as to reduce transportation costs. Due to the solid waste management challenges in the study area, including the possible development of a sanitary landfill in the future, innovative solutions are necessary to address the issues of sanitation and environmental protection. In this study, the authors have utilized GIS, MCDM approach, and AHP as the most suitable and feasible method to identify potential sites for landfilling. Several scholars and researchers have also employed GIS in conjunction with a systematic decision-making framework to identify appropriate landfill sites in their respective research areas presented in Table no. 1.

Reason for using GIS, MCDM and AHP

While employing GIS, MCDM, and AHP, multiple criteria or attributes and their related weights can be analysed in order to rank and prioritise potential landfill sites.[9,13-15] Geographic Information Science (GIS), which has the capacity to store and handle ample amount of spatial and attribute data, is an effective tool that helps to determine the best possible location for landfills.[16,7,17,1]

MCDA or multi-criteria decision analysis offers the benefit of evaluating a variety of factors, including combining factual information with expert opinion, and to find possible landfill sites, one of the most popular MCDA techniques is AHP or analytical hierarchy process.[18,1] AHP is a systematic methodology for managing and evaluating intricate decision-making processes, like choosing a landfill location,[1,19] and it establishes the relative importance or weight of criteria during the process of identifying the locations and enables consistent comparisons across elements.[20] Combining GIS and MCDA gives analysts the ability to systematically overlay an extensive spectrum of qualitative and quantitative norms just on one platform. These techniques have been especially beneficial in waste management research.[2]

Where the conventional method of data collection through manual labour can be time-consuming and susceptible to errors, incorporating GIS, MCDM and AHP can offer significant advantages in the landfill site selection process9 for Varanasi City. Firstly, it presents a clear and objective decision-making procedure that takes into account both qualitative and quantitative factors, thus reducing the likelihood of bias and ensuring a comprehensive investigation serves as the basis for the final decision.[9,21-24] Moreover, the integration of GIS, MCDM, and AHP enhances the process of determining a site by utilizing spatial data, allowing policymakers to easily understand the impact of various criteria on site selection and urban land use.[25,26] Considering the the abovementioned discussions, the objective of the current research is to determine the best possible landfill locations in the Varanasi district for the dumping of discarded solid waste items produced by Varanasi Municipal Area residents, using GIS, MCDA, and AHP.

Literature Review

Solid waste generation is an inevitable by-product of anthropogenic activity, whereas landfilling is one of the most affordable and convenient ways to dispose of municipal solid waste (MSW). Many academicians have endeavoured and executed their job to determine the ideal locations for landfilling. The work of academicians, who have used GIS, MCDA, AHP, and other techniques to locate landfill sites around the globe, is shown in Table 1. Based on the preceding brief review section, the majority of researchers have employed GIS-based MCDA and AHP applications to identify potential landfill sites. Consequently, the paper integrates the GIS-based MCDA and AHP techniques to find a landfill location where the MSW produced in Varanasi City may be safely disposed of.

Table 1: Significant Efforts Combining GIS and MCDM in Selecting a Landfill Site

Objectives	Method	Research Area
Landfill site location[1]	AHP and GIS	Behbahan, Iran
To offer substitute locations within the Guwahati Metropolitan Area[2]	GIS, and MCDA based AHP	Guwahati Metropolitan Area
Landfill site location[4]	WLC in a GIS, AHP	Gorgan City (Iran)
Landfill site selection[7]	GIS and MCDA, AHP-based pairwise comparison	Javanrood County in Iran
Landfill site selection[17]	GIS and MCDA	Al-Hashimyah Qadaa
Landfill siting[18]	GIS-Based Weighted Linear Combination and RS	Mafraq City, Jordan
Selection of the appropriate solid waste landfill site[19]	GIS and AHP	Beijing, China
Selection of a landfill site[27]	GIS and AHP, FTOPSIS	Memari Municipality, India

Finding appropriate locations for managing and disposing of solid waste[28]	GIS and MCDA	Akure, Ondo State
Locating solid waste landfill sites[29]	AHP and GIS	
look into an appropriate place to dispose of waste[30]	AHP and GIS techniques of multicriteria decision-making	Dejen town, Ethiopia
Locating sanitary permanent landfill[31]	GIS, AHP–CODAS and SAW–CODAS	Sivas City, Turkey
Landfill site selection[32]	GIS and TOPSIS	Bursa Province, Turkey
Identification of municipal landfill sites[33]	Multi-criteria GIS approach, Weighted Linear Combination and Ordered Weighted Averaging.	Bo, Southern Sierra Leone
Landfill site selection[34]	GIS, Fuzzy membership functions, AHP, OWA	Polog Region, Macedonia

Methods and Materials

The optimum places for a new municipal solid waste landfill in Varanasi have been determined by integrating a GIS-based MCDA technique and AHP. A detailed account of all the steps involved in the explanation of the approaches is provided below. In actuality, brief descriptions of the procedure are shown in the figure 1.

Geographical data are added to and modified in decisions made using MCDM method. It consists of expert's opinion, the input data, and the statistical modification of both. Eleven criteria for landfill siting have been included in the current study, which involved a thorough literature analysis. To complete the list of requirements, the MSWM Rule, 2016 has also been adopted. Expert opinion was used to assign a score between 1 and 5, where 1 signifies least suitability, while 5 denotes maximum suitability for each criterion. After standardising the criteria based on expert opinion and taking into account the land's suitability as a landfill, each prepared layer was assessed using a GIS platform.

A buffer zone of 20 km has been established surrounding the study area, accounting for the maximum transportation distance of solid waste from the city. In the east of research area, the buffer extended into the adjacent region, consequently, the buffer was aligned with the eastern boundary of the Varanasi District. As a result, the configuration of the area of interest, for which criteria maps have been generated, differs from that of the study region.

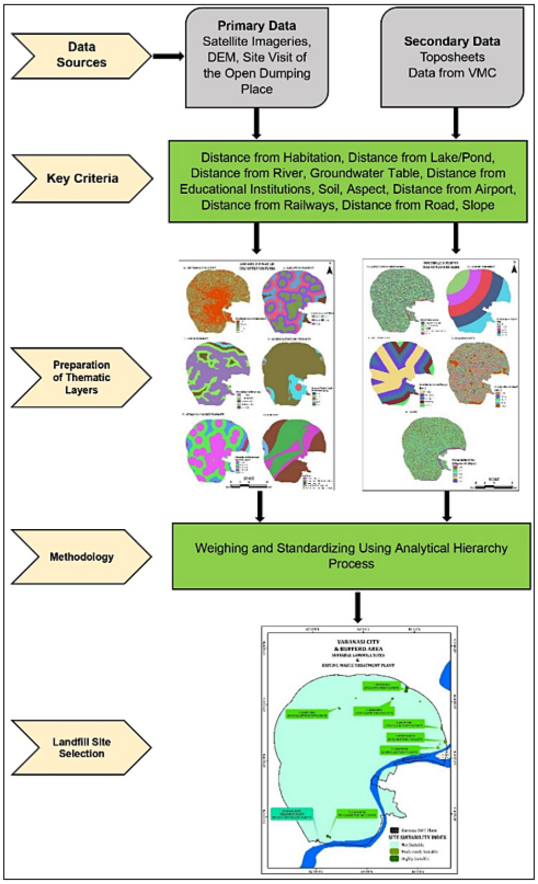

Fig. 1: Incorporated methodology and standards

Table 2: Sources of Data used in Criteria Mapping

Criteria	Sources
Base map	Survey of India Toposheets (OSM No. G44Q15, G44Q16, G44R3, G44R4, Scale-1:50,000)
Habitation	Extracted from LULC Map
Lake/Pond	Digitized from Toposheets and Map downloaded from NATMO
River	Digitized from Toposheets
Groundwater table	Aquifer Mapping and Ground Water Management Plan Varanasi District, Central Ground Water Board
Educational Institutions	Google Earth
Soil	NBSS & LUP, Regional Centre, New Delhi
Aspect	Derived from DEM downloaded from USGS Earth Explorer
Airport	Google Earth
Railways	Digitized from Toposheets
Road	Digitized from Toposheets
Slope	Derived from DEM downloaded from USGS Earth Explorer

Study Area

Varanasi City, the area under investigation, is situated on the western bank of the River Ganges, a waterway of significant religious importance. Eight development blocks and one municipal corporation area make up the administrative division of the Varanasi district. The city lies between 250 14’ 22’’ to 250 23’ 56’’ north latitude and 820 55’ 03’’ to 830 03’ 37’’ east of Greenwich, and it covers an area of 150.68 sq. km. Varanasi, which is situated in the heart of the Ganga Plain, has a nearly level terrain.[36] The topography of the district is essentially flat, despite the land's characteristic west-to-east inclination. The city lies on average 77 metres above mean sea level, with the highest point 83 meters being at the Rajghat plateau in the north, which is close to the Ganga-Varana River confluence, and approximately 72 metres along the Asi stream in the south.[37] The study area is characterised by a subtropical monsoon with seasonal fluctuations in climate, and in Koeppen's climatic categorization scheme, the climate is classified as Cwg type. The coldest month is usually January,

when the average maximum temperature is 23°C. Mid-December and early January might see temperatures as low as 5°C accompanied by dense fog. June, on the other hand, is scorching and has the highest average maximum temperature of the year, at about 35°C. It is not unusual for temperatures to exceed 40°C, and occasional heatwaves can push the mercury above 45°C. The average amount of rainfall in Varanasi each year is 110 cm, the majority of which falls between June to September during the southwest monsoon season. The month of August is drenched by south-west monsoon.[36]

The older alluvium and newer alluvium groups make up the city's geology. The more recent alluvium groups of Holocene age are located near river systems and feature newly deposited silt, clay, and loam as a result of recurring flood occurrences. The older alluvium groups date from the Middle to Late Pleistocene.[38] The city has excellent road connections with its surrounding neighbourhoods, is easily accessible by air, and is served by trains that travel from all major cities and metropolises in the country. Wind direction is an important factor in context of study, not discussed? (It has been discussed in aspect section 4.7)

Major Criteria

Criteria and Their Rating

Eleven criteria, such as habitat, rivers, lakes/ponds, groundwater tables, etc., have been embraced in this study to assess the compatibility of the proposed landfill site location and the current waste treatment facility. A range of tools for spatial analysis such as buffer, Euclidean distance, overlay, clip, reclassify, extract, etc. of ArcMap had been embraced to create map layers. The criteria and their rating have been depicted in the following table-3

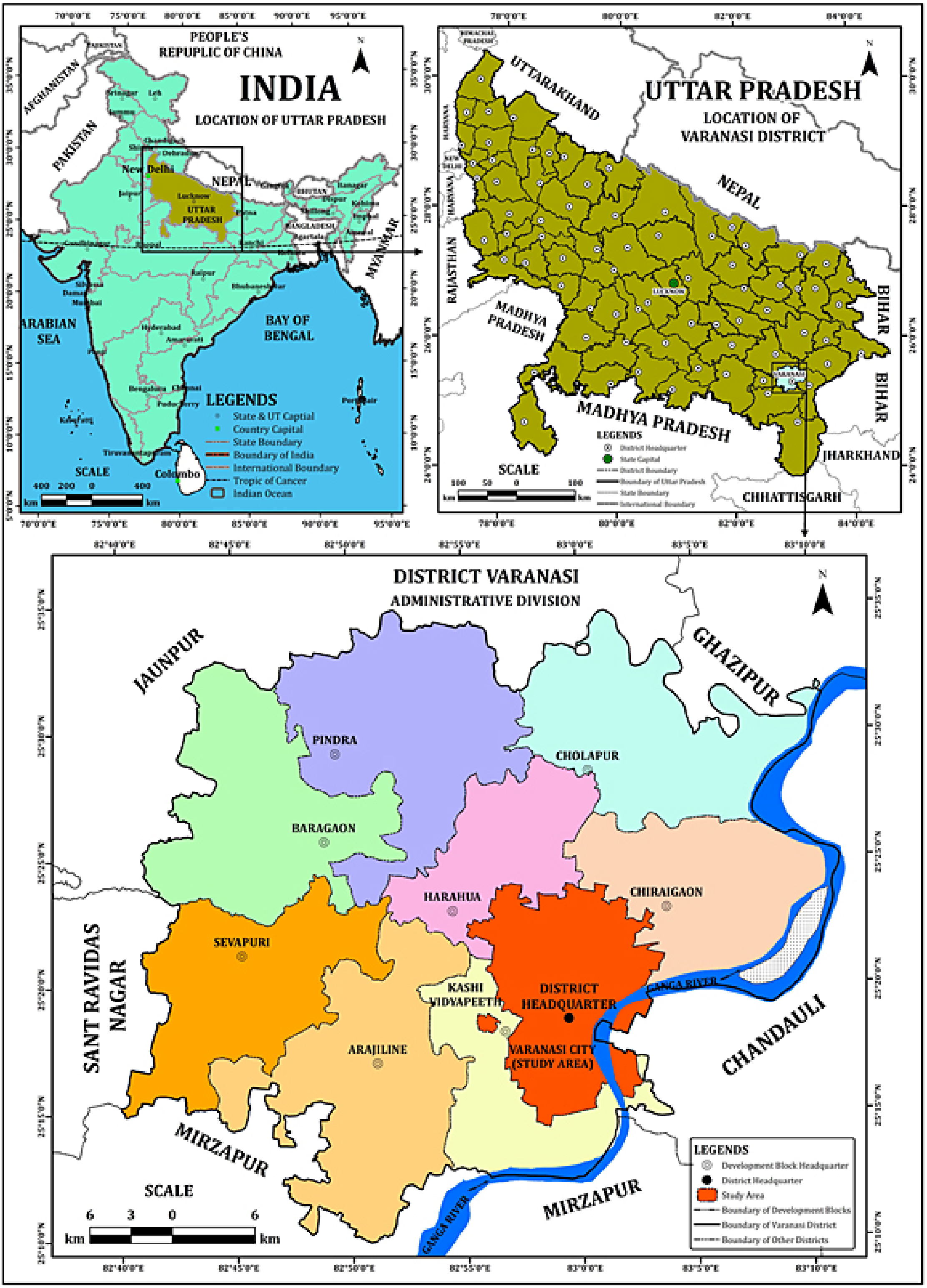

Fig. 2: A map depicting location of the research area

Table 3 :Criteria and its Rating

Criteria	Category	Rating	Weights
Distance from habitation	0-200 meter (MSWM Rule, 2016)	1	24%
	200-400 mt.	2	
	400-600 mt.	3	
	600-800 mt.	4	
	> 800	5	
Distance from Lake/Pond	0-200 meter (MSWM Rule, 2016)	1	19.4%
	200-400 mt.	2	
	400-600 mt.	3	
	600-800 mt.	4	
	> 800	5	
Soil type	Loamy to sandy	2	14%
	Loamy	3	
Distance from river	0-100 meter (MSWM Rule, 2016)	1	11.5%
	100-200 mt.	2	
	200-300 mt.	3	
	300-400 mt.	4	
	400-500 mt.	5	
Groundwater table	0-2 mt.	1	8.4%
	2-3 mt.	2	
	3-4 mt.	3	
	4-5 mt.	4	
	> 5	5	
Distance from educational institutions	1000–5600 mt.	5	6.9%
	750–1000 mt.	4	
	500–750 mt.	3	
	250–500 mt.	2	
	0-250 mt.	1	
Aspect	West-North-West, West, East	1	5.1%
	West-South-West, North-West	2	
	East-North-East	3	
	South-South-East	4	
	South	5	
Distance from airport	0-3 km.	1	3.5%
	3-20 km.	2	
	20 km. (MSWM Rule, 2016)	4	
	> 20 km.	5	
Distance from railways	500 mt.	5	3.3%
	400 mt.	4	
	300 mt.	3	
	200 mt.	2	
	100 mt.	1	
Distance from road	500 mt.	5	2.2%
	400 mt.	4	
	300 mt.	3	
	200 mt. (MSWM Rule, 2016)	2	
	100 mt.	1	

Slope (Degree)	8º-12º	4	
	12º-16º	3	
	4º-8º	5	1.7%
	16º-20º	2	
	> 20º	1	

Source: MSWM Rule, 2016, 39, 40

Assigning Weights to Criteria

The criteria employed in the aforementioned research are not of equal significance. Consequently, allocating weights to each criterion based on personal preferences has been deemed necessary.[8,38] The criterion weights utilized in this study were determined using the AHP, a methodology introduced in 1980 to facilitate decision-making processes.[35] The AHP employs a pair-wise comparison matrix, in which a scale of relative importance is utilized, with values assigned from a set.[47] Table 4 displays the degrees of importance and matching definitions.

Table 4: Elementary Scale of AHP

Degree of importance	Explanation
1	Equal importance
3	Moderate importance
5	Strongly important
7	Extremely important
9	Extreme importance
2, 4, 6, and 8	In between values
1/3, 1/5, 1/7, and 1/9 etc.	Inverse comparison values

The experts in the field of SWM have assigned the values in the matrix. After creating the pairwise comparison matrix, the following steps have been recruited to determine criteria weight

i. The sum of each column's values was determined.

ii. To create the normalized pairwise matrix, each column's elements were divided by the column's sum.

iii. The criteria weight was computed, which is the average of the components in every row of the normalized matrix.

iv. The value of λmax has been obtained.

v. The consistency index (CI) was calculated using Equation 1.

vi. The consistency ratio (CR) was computed using Equations 1 and 2 to verify the precision of the calculated value.

$$CI= \lambda_{max}-n/n-1 \qquad ...(1)$$

$$CR=CI/RI \qquad ...(2)$$

Where λ_{max}= weighted aggregate value multiplied by the criteria sum weight divided by the whole number of criteria

n = Number of criteria
CR = Consistency ratio
CI = Consistency index
RI = Random index

Table 5 displays a value of the random index. To meet the requirements, the CR should ideally be 0.10 or lower. In the event that the CR exceeds the desired value, it is necessary to revise a few pair-wise values until the required level is attained.

Table 5: Value of Random index

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.58

The subsequent stage of the landfill site selection procedure was to aggregate the criteria to ascertain whether the land was suitable after the criteria were standardized and the relative weights of each criterion were established. In the process of determining suitability, the weighted overlay technique (WOT) method has been frequently used to aggregate standardised criteria and their weights.[41] Since land use patterns cannot be changed for this kind of planning, weighted maps and constraint maps were used to assess ultimate suitability in the current study.

Site Selection Criteria

The current study aims to determine the landfill site location in the study area by taking into account eleven criteria, which include groundwater table, the distance from a lake or pond, a river, a settlement, a school or college, road, railways, airport, aspect, type of soil, and slope. Following a comprehensive analysis of the literature and the MSWM Rules, 2016, these criteria were established (Figure 3 and 4).

Distance From Habitation

To safeguard individuals from environmental hazards connected with landfill locations and to avert adverse consequences on the value of land and upcoming expansion, it is essential to situate the landfill site at a sufficient distance from residential or urban zones. The Turkish Solid Waste Control Regulations state (TSWCR 2002), the landfill cannot be positioned less than 10 km from an urban region.[42] However, as per MSWM Rules, 2016 it should be located far from 0-200 mt. from an urban area. The current analysis determined that a distance of at least 800 metres from a settlement was appropriate for the location of a landfill.

Distance from Lake/Pond

Leachate and offensive odours originate from landfills. They should therefore be kept well away from surface water bodies and wells. The data of pond/lake was retrieved from the Topographical maps (1:50,000). A Euclidean distance was placed between the water bodies at intervals of 0–200, 200–400, 400–600, 600–800, and > 800 metres. In the current study region, it was deemed safe to construct landfills more than 800 metres away from bodies of water.

Distance from River

The distance from rivers is one of the most crucial elements in deciding whether a location is appropriate for a landfill site or not. With the use of topographical maps, the vector layers of the rivers in the research region were created. According to the MSWM Rule,[43] landfills are not allowed to be 200 metres or closer to waterways. A landfill is better suited the further it is from a river. Places more than 500 yards away still have the maximum value of appropriateness.

Groundwater Table

The majority of daily tasks are completed with groundwater, which is also utilised for drinking. Leachate penetration poses a risk to the environmental and human health. Therefore, keeping a specific the distance from the sources of groundwater is important to avoid long-term environmental and health challenges. This criterion uses the straight distance from groundwater level to classify the entire land.[4] For the purpose, the data have been retrieved from the report “Groundwater brochure of Varanasi district, U.P.” prepared by scientist J.P. Gautam. Lands within ten metres of the water table are deemed inappropriate for landfill placement,[4] while the distance from 10 to 50 mt is considered most suitable to construct landfill site.

Distance from Educational Institutions

Avoiding educational institutions while choosing a landfill location was advised since it would negatively impact the institution's environment and aesthetic value,[13] decreasing the quality of life for academics and students and maybe causing respiratory problems due to the dangerous gases. Google Earth has been embraced to pinpoint educational institutions, and a Euclidean distance were generated as per the requirement.

Soil Type

The two main variables that determine the likelihood of groundwater contamination are soil permeability and soil porosity. High clay contents have a low permeability capacity, which reduces the amount of liquid pollutants that seep into the earth, making these soils ideal for low permeability applications.[44] The study made use of soil maps created by India's National Bureau of Soil Survey & Land Use Planning, Regional Centre Delhi (ICAR-NBSS&LUP). In this study region, two types of soil were identified: loamy and loamy to sandy. Loamy received the highest grade because of its comparatively low permeability.

Aspect

Wind direction is a factor that needs to be considered while building landfill sites since the stench produced by the waste has an impact on the adjacent populations. Because of this, it is always appropriate to place the landfill leeward or far enough away from the towns.[21] By utilising a DEM to create an aspect map, the wind direction of the research area was evaluated. The least desired areas are those that face the wind. Wind statistics of Varanasi indicate that the predominant wind directions are east (E), west (W), west-north-west (WNW), and west-south-west (WSW). As a result, places in the west (W), west-north-west (WNW), and west-south-west (WSW) have been assessed as having the highest degree of unsuitability, while other areas have been given higher ratings based on the suitability and wind direction.

Distance from Airport

The landfill is a haven for flies and birds, who linger over the discarded waste and could obstruct or endanger air traffic. As a result, location of landfills must take into account the distance from the landfill site. According to the MSWN Rule.[43] a landfill site should not be built within radius of 20 kilometres from an airport. Lal Bahadur Shastri International Airport in Varanasi is a factor which has been taken into consideration in the current study.

Distance from Railways

The railway track should not be next to the landfill. To ensure that optical interference and ground subsidence do not occur, it is essential to maintain a safe distance.[13] For this reason, several buffers were erected around the railway line at specific distances. Multiple buffers were constructed around the railway line within the following distances: 100, 200, 300, 400 and >500 mt. A buffer region of 0–200 mt. was excluded for landfill disposal. This 200 mt. area was not considered while selecting a landfill location to prevent visual and olfactory pollution.

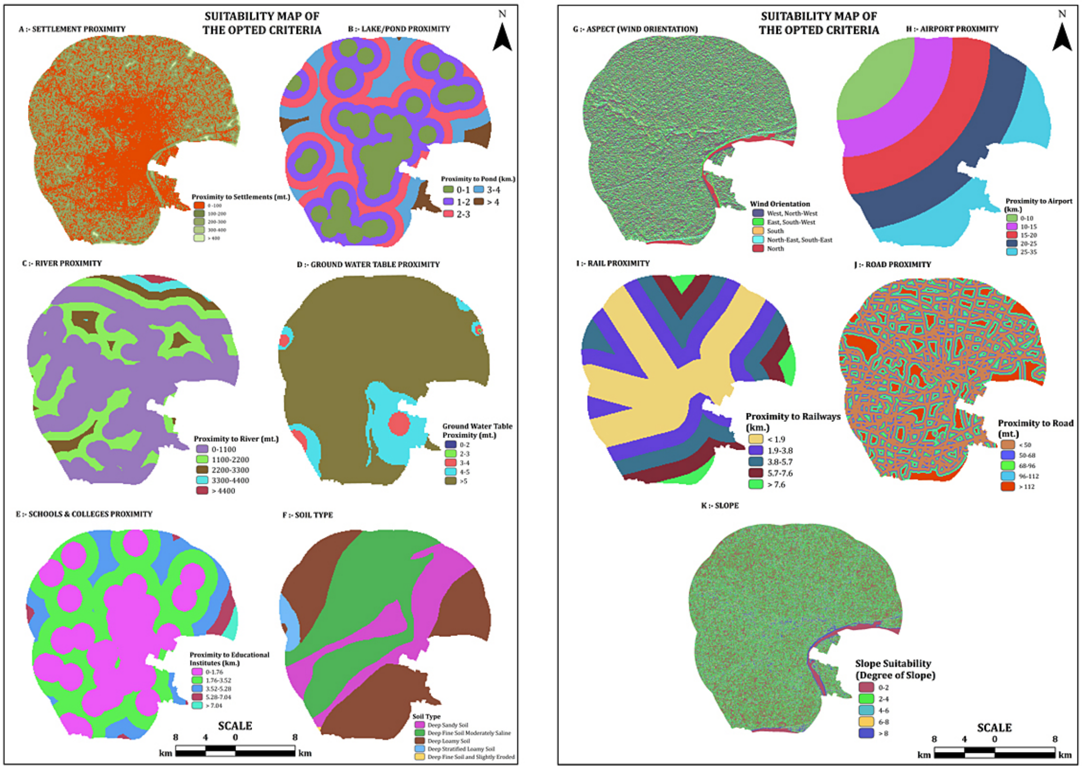

Fig. 2: Depiction map of Criteria

Distance from Road

Several scholars have assigned numerous criteria to ascertain the landfill's location from road. It is advised that landfill locations not be developed for more than one kilometer from major roads and highways to minimize the expenditures associated with constructing new roads as well as transportation and solid waste collection costs.[45] In addition, the MSWM Rule[43] establishes a 200-meter buffer between land fill site construction and the main road. Euclidean distances were established with linear distances of 100, 200, 300, 400, and 500 metres, respectively, taking into account the values, and appropriate grades were assigned.

Slope

Greater slopes are not seen to be appropriate for the development of landfill sites because they accelerate the transport of leachate into neighbouring areas and result in increased soil erosion.[2] Therefore, the choice and suitability for a landfill site decrease with increasing slope, and vice versa. The best places to dump solid waste are on slopes that are less than 10%, according to.[21,46] According to the study, the VMC should favour locations with the least slope, whereas land tracts with a slope of 4^0–8^0 were given the highest grade.

Results and Discussion

Computation of AHP

In the current study AHP has been embraced to identify the possible landfill site in Varanasi. For the purpose, Pair-wise comparison technique has been operated to assign weights. To generate the normalized pair-wise matrix, researchers employed the Pair-wise comparison matrix. This process involved calculating each column's total and then dividing individual elements within that column by the corresponding sum. The normalised matrix's average of each row was used to determine each criterion's weight, and habitation was assigned the highest weightage among all criteria.

In the next phase, the accuracy of the derived values was assessed by computing consistency. To this end, Table 6, which has not been normalized, was utilized. The criteria value was multiplied by each column value, and then the sum of each row's values was computed in order to get the weighted sum value. Subsequently, the weighted average value was determined for each row by dividing the weighted sum value by the respective criterion weight. The CR, CI, and λmax values were all determined.

With respect to the fraction of inconsistency, the value of CR is less than 0.10, and its value is 0.05261 (0.0526). Therefore, the matrix is highly consistent, and the AHP or Analytic Hierarchy Process can be employed in order to make decisions.

$$\lambda_{max} = \frac{Ratio\ of\ (1)(2)}{n}$$

$$\lambda_{max} = \frac{129.739}{11} = 11.79445$$

$$CI = \frac{\lambda_{max} - n}{n-1}$$

$$= \frac{11.79445 - 11}{11-1}$$

$$= \frac{0.79445}{10}$$

$$= 0.079445$$

Table 6: Pair-wise Assessment Matrix

PARAMETERS	(z1)	(z2)	(z3)	(z4)	(z5)	(z6)	(z7)	(z8)	(z9)	(z10)	(z11)
Distance from Habitation (z1)	1	2	3	3	4	4	5	5	6	7	8
Distance from Lake/Pond (z2)	1/2	1	2	3	4	4	5	5	5	7	7
Distance from River (z3)	1/3	1/2	1	2	3	3	4	4	5	6	6
Groundwater table (z4)	1/3	1/3	1/2	1	2	3	4	4	4	6	6
Distance from educational institutions (z5)	1/4	1/4	1/3	1/2	1	2	3	3	4	5	5
Soil (z6)	1/4	1/4	1/3	1/3	1/2	1	2	3	3	5	5

Aspect (z7)	1/5	1/5	1/4	1/4	1/3	1/2	1	2	3	4	4
Distance from Airport (z8)	1/5	1/5	1/4	1/4	1/3	1/3	1/2	1	1/2	3	3
Distance from Railways (z9)	1/6	1/5	1/5	1/4	1/4	1/3	1/3	2	1	2	2
Distance from Road (z10)	1/7	1/7	1/6	1/6	1/5	1/5	1/4	1/3	1/2	1	2
Slope (z11)	1/8	1/7	1/6	1/6	1/5	1/5	1/4	1/3	1/2	1/2	1

Table 7: Normalised Pair-wise Matrix

PARAMETERS	(z1)	(z2)	(z3)	(z4)	(z5)	(z6)	(z7)	(z8)	(z9)	(z10)	(z11)	Sum of Row	Criteria Weight
Distance from Habitation (z1)	0.2856	0.3832	0.3659	0.2748	0.2529	0.2154	0.1974	0.1685	0.1846	0.1505	0.1633	2.6421	0.240
Distance from Lake/Pond (z2)	0.1428	0.1916	0.2439	0.2748	0.2529	0.2154	0.1974	0.1685	0.1538	0.1505	0.1429	2.1345	0.194
Distance from River (z3)	0.0952	0.0958	0.1220	0.1832	0.1897	0.1616	0.1579	0.1348	0.1538	0.1290	0.1224	1.5454	0.140
Groundwater table (z4)	0.0952	0.0637	0.0610	0.0916	0.1264	0.1616	0.1579	0.1348	0.1231	0.1290	0.1224	1.2667	0.115
Distance from educational institutions (z5)	0.0714	0.0479	0.0407	0.0458	0.0632	0.1077	0.1184	0.1011	0.1230	0.1075	0.1020	0.9287	0.084
Soil (z6)	0.0714	0.0479	0.0407	0.0305	0.0316	0.0539	0.0789	0.1011	0.0923	0.1075	0.1020	0.7578	0.069
Aspect (z7)	0.0571	0.0383	0.0305	0.0229	0.0211	0.0269	0.0395	0.0674	0.0923	0.0860	0.0816	0.5636	0.051
Distance from Airport (z8)	0.0571	0.0383	0.0305	0.0229	0.0211	0.0180	0.0197	0.0337	0.0154	0.0645	0.0612	0.3824	0.035
Distance from Railways (z9)	0.0476	0.0383	0.0244	0.0229	0.0158	0.0180	0.0132	0.0674	0.0308	0.0430	0.0408	0.3622	0.033
Distance from Road (z10)	0.0408	0.0274	0.0203	0.0153	0.0126	0.0108	0.0099	0.0112	0.0154	0.0215	0.0408	0.2260	0.022
Slope (z11)	0.0357	0.0274	0.0203	0.0153	0.0126	0.0108	0.0099	0.0112	0.0154	0.0108	0.0204	0.1898	0.017

Consistency Check= 7%

CR=0.079445/1.51

CR= 0.05261

CR 0.053< 0.10

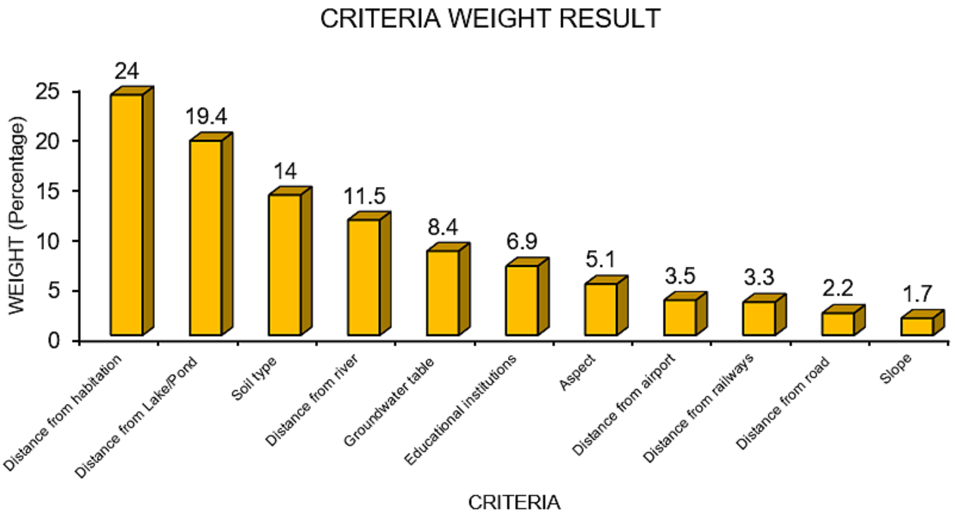

Fig. 3: Criteria Weight Result

The value of CR is 0.05261 (0.053) for the consistency proportion CR is < 0.10, which is standard47. Therefore, the matrix is relatively consistent, and the process of decision-making can be carried out utilizing AHP. The criteria weights can be used by the decision-makers to decide the importance of criteria.

Location of Landfill Site

Landfill site location in city for an effective solid waste management, is a task which must be practiced precisely and prudently. In the present study, an operation for landfill site location has been executed using GIS-based MCDA-AHP technique for Varanasi city. Eleven factors in total—such as habitation, lakes/ponds, rivers, groundwater tables, educational institutions, soil, aspect, and distance from airports, railroads, and roads—have been considered to determine the final placement of landfill. The optimal place for landfilling has been determined to be 0.1888% of the overall area, or 1.058 sq. km. Other than that, 0.172% (0.965 sq. km.) is a moderately appropriate location, while 99.639% (558.512 sq. km.) is not suitable owing to nucleated concentration of settlements, and close proximity to other criteria (Figure-5, Table no. 8).

Table 8: Calculation of Landfill Site Suitability

Value	Area in Per cent	Area (sq. km.)
Not Suitable	99.63901	558.5122
Moderately Suitable	0.172165	0.965045
Highly Suitable	0.188826	1.058437
Total	100	560.5357

Source: Computed by the author

Furthermore, seven locations have been identified for the proposed landfill sites, including Mustafabad, Chandpur, Chhitauni, Jalhupur, Kakarhia, and Khatahna. Among these, the two most suitable locations are Khutahna (0.43 square kilometers) and Mustafabad (0.21 square kilometers), both of which have an area larger than the current Karsara WTP (as shown in Table no. 9 and Figure 5). Lastly, it is essential to conduct a site walkover prior to selecting a final location for the landfill site.

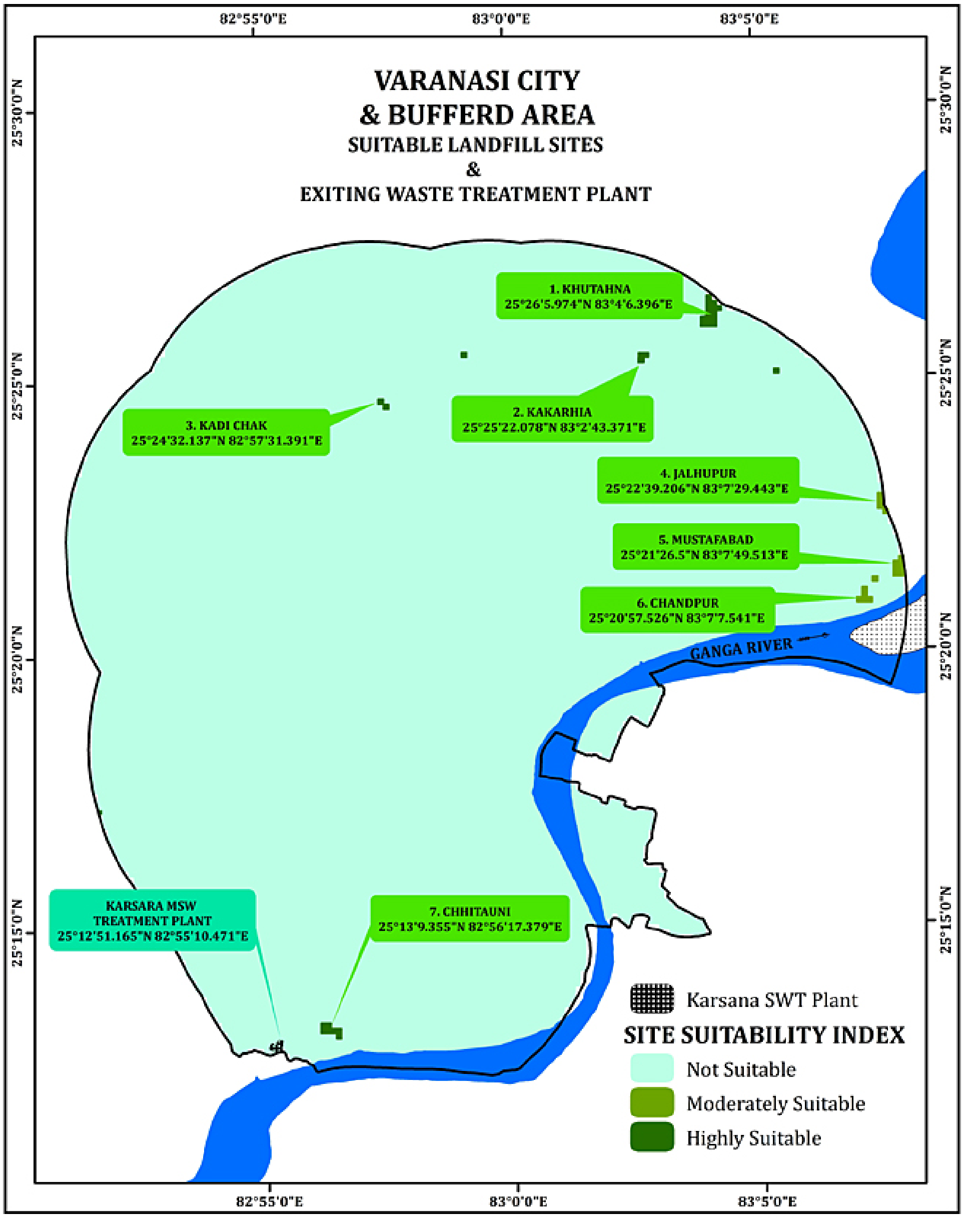

Fig. 4: Location of some suitable and alternative Landfill Sites

Table 9: Proposed Landfill Sites and their Locations

No.	The Proposed Sites' Names	Area (sq. km.)	Coordinates
1.	Khutahna	0.43	25°26'5.974"N 83°4'6.396"E
2.	Kakarhia	0.09	25°25'22.078"N 83°2'43.371"E
3.	Kadi Chak	0.06	25°24'32.137"N 82°57'31.391"E
4.	Jalhupur	0.13	25°22'39.206"N 83°7'29.443"E
5.	Mustafabad	0.21	25°21'26.5"N 83°7'49.513"E
6.	Chandpur	0.15	25°20'57.526"N 83°7'7.541"E
7.	Chhitauni	0.22	25°13'9.355"N 82°56'17.379"E
Existing Plant	Karsara MSW Treatment Plant	0.12	25°12'51.165"N 82°55'10.471"E

Conclusion

One of the oldest and living cities in India is Varanasi, and most of its growth and developments have happened at random, particularly in its central region. A number of variables, including living standards, caste systems, seasonal fluctuations, festivals, marriage seasons, and an influx of pilgrims and travellers, influence Varanasi's MSW generation cycle. All of these set the stage for experiencing the city's complex and varied solid waste composition.

This study employed spatial analytic techniques, namely GIS, Analytic Hierarchy Process (AHP) and Multi-Criteria Decision-Making (MCDM), to address the issue of landfill site selection in Varanasi City. Numerous variables and an unbiased method have been considered to identify the best possible location for landfill site to maximize the sustainability. A precise and systematic work becomes inevitable in the milieu of swift urbanization.

Suitability maps were generated with the assistance of multiple variables, i.e. proximity to water bodies, residential distance, road, railway etc. to aid decision-makers in selecting landfill sites. Including AHP enhanced the decision-making framework's robustness by assigning appropriate weights to these criteria based on their relative importance.

The analysis yielded several key findings. Firstly, Varanasi exhibits some locations which are most suitable to locate landfill sites, whereas few sites are moderately suitable and a vast area falls under not suitable category due to several constraints. It is also notable that Karsara WTP is located in an unsuitable location.

Utilizing a combination of spatial analysis and the Analytic Hierarchy Process (AHP), this research has pinpointed optimal landfill locations in Varanasi City that meet both technical requirements and community preferences. It is crucial to note that the process of selecting landfill sites is dynamic and requires regular monitoring and evaluation to adjust to changing urban conditions and environmental factors.

Therefore, to mitigate the challenge, the selection of a landfill site must be conducted with precision, taking local factors into consideration. If the findings of the aforementioned study are implemented effectively, the residents of Varanasi City may experience a cleaner and more sustainable environment, potentially realizing the aspiration encapsulated in the slogan "Swachh Kashi, Sundar Kashi" (Clean Kashi, beautiful Kashi).

Limitations

The current work has provided some invaluable insights to identify suitable locations for the landfill site selection employing spatial analysis techniques and MCDM with AHP in the unique context of Varanasi City. While acknowledging that the result is not perfect and may encounter difficulties, it is important to acknowledge the importance of the findings even in light of their limitations. A few limitations that need to be taken into account and improved upon in future research projects are subjectivity in the weighting of the criteria, financial restrictions, and the availability and quality of data.

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Conflict of Interest

The authors declare no conflicts of interest, whether academic or commercial.

Data Availability Statement

The location map was developed by the author using toposheets and shape files obtained from the official website of the Survey of India. Furthermore, the proposed dumping sites were identified using Google Earth.

Ethics Statement

It is important to note that this study did not involve any experiments on humans and animals.

Informed Consent Statement- This study did not involve human participants, and therefore, informed consent was not required.

Author Contributions

- **Dr Awadhesh Kumar:** was responsible for formulating the paper, analysing the data, performing GIS analysis, and composing the manuscript.
- **Prof. Narendra Kumar Rana:** devised the theoretical framework, supervised the research, and reviewed the manuscript.
- **Mr. Anand Kumar:** digitized the shapefiles according to the specified requirements, created the maps, and contributed to refining the manuscript.

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