

Analytical Hierarchy Process Tool in Google Earth Engine platform : A case study of a tropical landfill site suitability

Soham Bhattacharya

NIT-Durgapur: National Institute of Technology Durgapur

Surajit Ghosh (✉ surajitghosh.ind@gmail.com)

International Water Management Institute <https://orcid.org/0000-0002-3928-2135>

Soumya Bhattacharyya

NIT-Durgapur: National Institute of Technology Durgapur

Research Article

Keywords: Google Earth Engine (GEE), GEE App, Analytical Hierarchy Process (AHP), Municipal Solid Waste (MSW), Suitability Analysis

Posted Date: November 2nd, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-795406/v1>

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Version of Record: A version of this preprint was published at Environmental Monitoring and Assessment on March 14th, 2022. See the published version at <https://doi.org/10.1007/s10661-022-09878-w>.

Abstract

Kolkata being a metropolitan city in India, has its main Municipal Solid Waste dumpsite situated at Dhapa just adjacent to the East Kolkata Wetlands Ramsar site. The current prevalent situation at Dhapa is open dumping leading to various contaminations and hazards putting forth the need to look for alternative sites where the landfilling operation can be shifted to using scientific methods. A User Interface (UI) based Analytical hierarchy process (AHP) tool has been developed within the Google Earth Engine (GEE) cloud platform to find out the alternative dumping sites using geospatial layers. AHP function is not available as a native algorithm or developed by any researcher in GEE. The tool has three major functionalities, of which the first one handles the UI elements. The AHP procedure is within another function, and the last function integrates the AHP coefficients to the layers generating the final suitability layer. Users can also upload comparison matrix as GEE asset in the form CSV file which gets automatically integrated into the AHP to calculate the coefficients and consistency ratio to generate the spatial suitability layers. This approach showcases a generalized AHP function within the GEE environment, which has been done for the first time. The tool is designed in the cloud platform which is dynamic, robust and suitable for use in various AHP-based suitability analysis in environmental monitoring and assessment.

1. Introduction

With the remarkable advances in the Earth Observation (EO) data acquisition techniques and plenty of Earth Observation missions, the quantity of Remotely Sensed (RS) data has been increasing from exabyte to petabyte-scale every year. Some of the RS data repositories are USGS Explorer, Bhuvan, NASA's portal. In view of the present and future mission, much higher spectral, spatial or temporal resolution sensors would probably generate data of higher dimensionality. On the other hand, planetary-scale applications in earth science or environmental studies may inevitably aggravate the complexity of data and its processing. Therefore, RS data have been accepted as Big Data not only because of the extreme data volume but also for the complexity and variety the data gives rise to (Wang et al., 2019). The incorporation of Big Data analytics and Cloud computing to facilitate large-scale scientific applications has revealed an easy-to-use approach to the extreme computational and storage challenges. This is hugely beneficial because now anyone can view and process those data without owning costly and powerful hardware.

One such example is Google Earth Engine (GEE) which is the backbone of this study. GEE is a cloud-based service that is free for research purposes without downloading and managing data locally (Gorelick et al., 2017). Google cloud-computing infrastructure is the backbone of the platform, and Google itself handles computations. All are automatically performed on the CPUs and GPUs of Google (Gorelick et al., 2017). Since GEE was mainly developed and optimized for analysis on geospatial data, it can process large amounts of RS data in large geographical scales and long temporal coverage (Ravanelli et al., 2018). Thus, it is a great tool for analyzing regional or global-scale applications. Various datasets are already available within GEE, and users can also easily upload and use their own datasets and scripts to

generate the products on the fly (Kumar and Mutanga., 2018). GEE stores and analyzes RS imagery based on a pyramiding and tiling concept (Fuentes et al., 2019). Every image imported into GEE has its own pyramids at different resolutions, making the processes and visualizations much faster and smooth (Gorelick et al., 2017). Every function and option within GEE processes images on 256×256 tiles. Different scales of the pyramid are used at different zoom levels enabling GEE to process and show large areas of processed images quickly and efficiently (Amani et al., 2020). Pyramids representation means to break down the input image into multiscale representation which provides a series of residual images and one approximate image. This process provides access to the enhanced image features of various sizes (Kaur et al., 2020).

GEE is a prime example of cloud computing with many inbuilt and native functions and commands that make it very simple to code. GEE has a lot of worked-out examples and an active community. The best part is that even though GEE is based on programming, which might seem daunting at first, it uses JavaScript (JS) and Python script which are very established and mature discipline. GEE has many inbuilt functions and datasets, but the Analytical hierarchy process (AHP) which is a function widely used in different decision-making problems (Saaty 1980, Alanbari et al., 2014, Acharya et al., 2019) has not been implemented as a native algorithm or developed by any researcher. In the present study, the AHP method has been developed in GEE environment using JS. The user needs to provide the CSV files containing the pairwise comparative scoring values as GEE asset, and the code will automatically put them in the matrix calculation of AHP and calculate the individual weightage coefficients. These coefficients are then used to process the associated layers and ultimately provide us with a map highlighting the suitable sites located within the stipulated area of concern. Landfill suitability analysis as a case study has been taken up in the present study to highlight the technological prowess of GEE which may further help other environmental applications based on AHP.

2. Tool Development

The whole procedure AHP method was developed within the GEE environment using JS (Fig. 1). Separate functions have been set up for import dataset, AHP process, display the results and UI components. The development and work have been described in the following sections.

2.1. General understanding of AHP procedure

The AHP being a well-known form of Multiple-Criteria Decision-Making (MCDM) is an effective and established tool to deal with decision making, which are complex in nature. It might help users set their preferences and make the best decision (Saaty, 1980). AHP helps to provide both subjective and objective parts of a decision by reducing the said decisions to a group of pairwise comparative values. On top of this, AHP incorporates a useful method to check the consistency of the users pairwise comparative scoring, thus reducing the tendency to be biased while carrying out the decision-making process. The AHP at first considers a set of main criteria. Each of these will have alternative options from which the best decision can be made. First, a weightage for each criterion is generated according to the user's

pairwise comparisons. A higher score to that criterion means its importance is greater as compared to the other ones. Next, for each criterion, a score gets assigned to each option according to the user's pairwise comparisons. Lastly, the AHP process combines the weightage for the criteria and the scores. This provides a global score for each option and a respective ranking. The global score for an option is a weighted sum of the scores it obtained with respect to all the criteria. The values of (a_{ij}) when $(i = 1, 2, 3, \dots, m)$ and $(j = 1, 2, 3, \dots, n)$ are used to indicate the performance values in the rows and columns of the matrix. Here a_{ij} is the element of the row (i) and column (j) of the matrix.

$$a_{ji} = \frac{1}{a_{ij}}$$

A typical comparison matrix for the criteria is represented as follows in a matrix formation:

$$\begin{bmatrix} a_{11} & a_{12} \dots a_{1n} \\ a_{21} & a_{22} \dots a_{2n} \\ \cdot & \dots \\ \cdot & \dots \\ a_{m1} & a_m \dots a_{mn} \end{bmatrix} \begin{bmatrix} W_1 \\ W_2 \\ \cdot \\ \cdot \\ W_n \end{bmatrix}$$

The eigenvectors for each row gets calculated. It is done by multiplying the value for each criterion in each column in the same row. The matrix to be considered is the original pairwise comparison matrix and not the normalized one. Then those are applied to each row. This is shown as below (Saaty, 1980):

$$Eg_i = (a_{11} \times a_{12} \times a_{13} \times a_{14} \dots \times a_{1n})^{\frac{1}{n}}$$

Where, Eg_i = eigenvalue for the row (i) ; n = number of elements in row (i)

normalizing the eigenvalue to 1 (divided by their sum) gives the priority vector or AHP weight (Saaty, 1980), as follows:

$$Pr_i = \frac{Eg_i}{(\sum_{i=1}^n Eg_i)}$$

The maximum lambda (λ_{max}) or maximum eigenvalue is obtained from the summation of products between the sum of columns of the reciprocal matrix and each component of the priority vector, as shown in the following formula (Saaty, 1980): $\lambda_{max} = \sum_{j=1}^n \left[W_j \sum_{i=1}^m a_{ij} \right]$

Here a_{ij} represents the criteria in each column in the matrix, and W_j is the value of weight for each criterion corresponding to the priority vector in the decision matrix.

As stated before, AHP incorporates a technique to check the consistency for the evaluations made by the user when creating each of the pairwise comparison matrices for the process. The technique provides the computation of a suitable consistency index (CI).

The consistency index gives the equivalent of the mean deviation of each comparative element and the standard deviation of the evaluation error from the ones that are true. This can often turn out to be larger than the value describing a fully consistent matrix in order to provide a measure of severity of this deviation (Saaty,1980).

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

Where, CI is the consistency index, n is the size or order of the matrix.

The consistency ratio (CR) is found by dividing the consistency index value (CI) by the random index (RI) value, and n being the size of the matrix. Table 1 shows the mean random index value RI for a matrix with different sizes (Saaty, 1980). A perfectly consistent decision-maker should always obtain CI=0, but small values of inconsistency may be tolerated.

Table 1
Random inconsistency indices for different values of (n)

Criteria	3	4	5	6	7	8	9	10
RI	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.51

$$CR = \frac{CI}{RI}$$

If the ratio between CI and RI (CR) is greater than 0.10, the user has to re-evaluate his/her initial scoring input. If less than 0.10, then consistent values will be generated as the ratio value goes lower.

There can be any number of criteria that can be taken into consideration for the procedure of landfill site selection. But the following criteria were taken based on the location, datasets availability and importance (Chabuk et al., 2017). Further study using these criteria is also possible, as is adding more criteria.

2.2. Implementation of AHP in GEE

GEE provides an integrated database that is easy to implement and work with, can be easily integrated or called into user codes and requires no additional effort except an account. This database was extensively used within the code; various functions that are natively supported were also used a lot for developing the AHP procedure. The whole coding was done using JS Code Editor.

2.2.1. Functions and Algorithms

The elements that can be called functions, algorithms, layers and other entities are all server-side elements. These can be included within codes by using *ee.Number* for some number calling, *ee.Array* for arrays or *ee.Image* for image or image collection from GEE datasets. The interactive UI is what greets the user once the code is run. It includes information over each input box, which has been implemented using *ee.Textbox*, telling the user what to input, default values have also been set where required using if conditions along with checkboxes (*ui.Checkbox*) to activate or deactivate “region selection” and “suitability layer download” functions.

The pairwise comparative scores for both criteria and sub-criteria need to be input into a CSV file, then uploaded within GEE as an asset, the corresponding asset IDs need to be provided in their respective input boxes along with the criteria names. The code simply uses *.getValue* command to extract the input data from the asset (above mentioned CSV file) linked in the textbox by the user. A sample CSV file is also linked for example purpose. The button just below the criteria name input boxes is used to check the CR value for the criteria which also displays a message box in the Map UI telling the user if the CR is less than or greater than 0.10. This button, implemented with *ui.Button* function, calls the AHP function, which extracts the user inputs data from the criteria CSV file, puts them inside the matrix calculation procedure, finds the coefficients for each of the input layers. This is then passed on to the layers in another function where the coefficients get multiplied with the layers and added to generate the suitability maps. Besides these commands like *ui.Panel* for UI panel creation, *ui.Label* for typed lines within the UI was also used, as discussed below.

2.2.2. GEE layers and Datasets

GEE layer Databases and the option for user imported layers is one of the main reasons that make GEE so comprehensive. GEE has long term datasets of different sensors and models' outputs, and those are updated regularly. GEE database was used to include layers like Slope, Temperature, Precipitation, Population and Land use into the code using native commands like *ee.ImageCollection* and *ee.Image* within the first function. Any function or command starting with 'ee' is termed a proxy used to manipulate or use objects from the server-side of GEE being with the client-side. These premade layers that are natively supported within the platform make it very easy to implement.

One can also import and use user-defined or created layers in either raster or vector form for data that are not covered within the GEE database. There is also support to convert vector to raster within GEE, which was also used. For example, layers like roads, water bodies, protected zones, geomorphology and groundwater were all externally created and ingested into GEE as assets and converted those vector layers into raster layers. The first function also handles the AHP calculation for the reclassified values or sub-criteria for the individual criteria, wherein the ranges or reclassified values are scored from 1-9 based on their relative importance in a similar fashion as that of the main AHP function as below. The data sources for each layer have been given in Table 2. Here for each sub-criteria, a coefficient from the sub-criteria AHP calculations is obtained. These two need to be multiplied to get the final output for each

layer. But simple *.multiply* would not work directly as the coefficients are arrays and the layers are images. To combat this, the array values were converted to images which were then ready to be multiplied. But the output still needs to be reclassified. This was also done here using *.gte*, *.gt*, *.lte*, *.lt* and *.eq* functions as required to provide ranges that are used to classify the layer. The ranges for reclassification were so chosen to have a better variation of the criteria within the area of interest, but can be changed as per the need of the user within the code. After the reclassification, the array converted to the image was multiplied by the imported layer. This was then added to the map or display using *map.addLayer*. Colour palettes were also chosen as well as the mapped output was clipped to keep the result within our area of interest. As stated earlier, vector to raster conversion was done within GEE for the user imported layers. Four layers of slope, temperature, precipitation and Land use were imported directly from GEE datasets. More specialized layers like road, water body and protected zone proximities, groundwater layer, geomorphologic layer were imported as Assets into GEE, which shows the flexibility of GEE using users to import layers of their choice in various formats. All of these layers are then added together to make one single layer to be displayed in the map view as the suitability layer.

Table 2
Criteria (Data), Source and its reclassification scheme

Criteria	Data source	Sub-Criteria	Classified Values*	References
Slope (degree)	<i>SRTM (GEE)</i>	<i>0 – 0.8</i>	<i>9</i>	Ali et al., 2020
		<i>0.8 – 1.3</i>	<i>7</i>	
		<i>1.3– 2</i>	<i>5</i>	
		<i>2 - 5.20</i>	<i>3</i>	
		<i>5.20 – 12.66</i>	<i>1</i>	
Population density (person/sq km)	<i>CIESIN (GEE)</i>	<i>1 - 10</i>	<i>9</i>	CIESIN - Columbia University. 2018
		<i>10 – 50</i>	<i>7</i>	
		<i>50 – 100</i>	<i>5</i>	
		<i>100 – 500</i>	<i>3</i>	
		<i>500 - 50,000</i>	<i>1</i>	
Precipitation (mm)	<i>CHIRPS (GEE)</i>	<i>0 – 25</i>	<i>9</i>	Funk et al., 2015
		<i>25 – 26</i>	<i>7</i>	
		<i>26 – 27</i>	<i>5</i>	
		<i>27 – 28</i>	<i>3</i>	
		<i>> 30</i>	<i>1</i>	
Temperature (deg C)	<i>MODIS (GEE)</i>	<i>25.90 – 28.95</i>	<i>9</i>	Ali et al., 2020
		<i>28.95 – 30.74</i>	<i>7</i>	
		<i>30.74 – 32.04</i>	<i>5</i>	
		<i>32.04 – 33.39</i>	<i>3</i>	
		<i>33.39 – 37.01</i>	<i>1</i>	
Buffer around Surface Water bodies (m)	<i>Landsat 8 (GEE)</i>	<i>0 - 200</i>	<i>1</i>	Ali et al., 2020
		<i>200 – 400</i>	<i>3</i>	
		<i>400 – 600</i>	<i>5</i>	
		<i>600 – 800</i>	<i>7</i>	
		<i>800 - 1000</i>	<i>9</i>	

** 1 is less preferred, 9 is most preferred*

Criteria	Data source	Sub-Criteria	Classified Values*	References
Buffer around POI (m)	<i>Google Earth</i>	<i>0 - 200</i>	<i>1</i>	Derived from Ali et al., 2020
		<i>200 – 400</i>	<i>3</i>	
		<i>400 – 600</i>	<i>5</i>	
		<i>600 – 800</i>	<i>7</i>	
		<i>800 - 1000</i>	<i>9</i>	
Buffer around Road (m)	<i>Google Earth</i>	<i>0 - 100</i>	<i>1</i>	Ali et al., 2020
		<i>100 – 200</i>	<i>3</i>	
		<i>200 – 300</i>	<i>5</i>	
		<i>300 – 400</i>	<i>7</i>	
		<i>> 400</i>	<i>9</i>	
Geomorphology	Nath et al., 2014	<i>Older Levee</i>	<i>9</i>	Ali et al., 2020
		<i>Deltaic Plain</i>	<i>7</i>	
		<i>Younger Levee</i>	<i>5</i>	
		<i>Swampy Land</i>	<i>3</i>	
		<i>Interdistributary Marsh</i>	<i>1</i>	
Ground water (m)	<i>CGWB</i>	<i>0 – 7</i>	<i>9</i>	Current study
		<i>7 – 12</i>	<i>7</i>	
		<i>12 – 17</i>	<i>5</i>	
		<i>17 – 21</i>	<i>3</i>	
		<i>> 21</i>	<i>1</i>	
<i>* 1 is less preferred, 9 is most preferred</i>				

The second function handles the AHP, wherein the user inputs are accepted into the code as CSV files; these are then passed onto the different variables via *parseFloat()* (Fig. 3) function to convert the accepted string into returning floating-point number. Inputs or data taken from the user using *ui.Textbox* are all in string, so no mathematical calculations can be done while the data is in String format. To solve

this *parseFloat* a native JS command was used, which parses the String input and returns a floating-point number with which further operations can be done. The reciprocal of these criteria scores also need to be present in the CSV file. All of these are then put into an Array with *ee.Array* function to bring the matrix formation of AHP in the code, the upper triangular numbers being the inputs, diagonals being 1 and lower triangular numbers being the reciprocals of the user inputs. These are then sliced up or separated from the above array into individual arrays so that the calculation can be done using each separate numbers. GEE provides many Client-side libraries to be included into codes and expand the usability. These were used extensively throughout. Within the AHP function, functions like *.add*, *.divide*, *.multiply* were used to do the whole operations on the different Arrays. So within the AHP function, we get different coefficients as outputs for each of the layers or criteria. The Consistency Ratio (CR) acts as the accuracy check to assess if the inputs are optimized or not. These are then passed onto all the other main functions to be used in those. It is necessary to pass the value of one computed variable from one function to another function to be used further.

Next comes the function that handles the UI operations. This has been made with wide usability and user-friendliness in mind. The user will be able to get the suitability layer with minimum input. With the inclusion of the CSV input method, the usability has been simplified further. The user can download the CSV template file, make two CSV files for criteria and sub-criteria respectively, upload and provide the asset IDs within the UI. The code handles the rest. The important headings have been highlighted in bold letters and clear instructions. All the imported assets used in the study have been made accessible to all.

There is also a tertiary function which is mainly for convenience purposes during the coding and debugging stage. It handles all the printing of various variables from the AHP function, mainly into the console.

2.2.3. AHP and its implementation

AHP is the backbone of the whole operation wherein it is being used to evaluate the possible outcomes from among the input layers according to the pairwise scoring being provided by the user according to their priority or decision. The AHP procedure or function that has been created here within GEE using native functions or commands. The whole system of the user inputting the comparative scores through CSV files, using those to run the AHP and providing coefficient values with CR value for accuracy checking, has been done exclusively within GEE. It is currently working with nine criteria in the present study, but in the future, it can easily be adapted for more than that, simply by slightly customizing the current code. The process has been kept simple and to the point in which the AHP function first calls the raster layers and pairwise comparison values as input from the user and transforms them to the array. These are then run through the whole process of AHP calculation in the matrix format, and the coefficients, CI and CR values are generated accordingly. These are then called into other functions for further processing to generate the suitability layer.

2.2.4. JavaScript (JS), Client and Server sides of GEE

The client libraries section is the API reference for both JS and Python clients. The code Editor section handles functionality available throughout the online IDE i.e. Earth Engine code editor for JS and the REST API section which handles the Earth engine restful API. The use of JavaScript Object Notation (JSON) architecture for receiving the computed data from the GEE server to the user console, JS is being used throughout the coding process, and it becomes necessary to differentiate between JS and GEE objects. The server handles the calculations, and the client-side simply calls that answer or result, which gets to the user in JSON) format, which is a format for storing or transporting data. JSON is often used in JS to send data from the server-side to the client-side, which is happening in this code. JSON is a data-interchange format, lightweight, easy for humans to read and write and also easy for machines to parse and generate. GEE has two sides or formats, client and server sides. It's best not to intermingle them. But one can use proxy objects on the client-side to manipulate server-side objects. Anything starting with 'ee' is a proxy object which doesn't itself contain any data, but it helps to call or use server functions within the client-side, like *ee.Image* or *ee.ImageCollection*, *ee.FeatureCollection*, etc. So accordingly, server-side data like maps, datasets, algorithms that were to be included were called as above into the client-side, the GEE code that was developed. Within the AHP function, *ee.Array* function was used to access the array functionality from the server-side and further mathematical operations were done.

2.3. UI development in GEE

The UI is simple with a minimalistic approach. The first input box asks the number of criteria from the user; the next two textboxes accept the Asset IDs for the two .csv assets that need to be uploaded by the user containing all the comparative scores for the criteria and sub-criteria. The next 9 text boxes will have to be filled with the names of the 9 criteria that are within the header of the sub-criteria CSV file. Then all the user has to do is click on the button below to run the main AHP function to check the CR value. The CR check dialogue will be visible in the Map UI, next the user can opt for ward wise visualization or whole area for the suitability map layer along with a download function.

GEE is the environment where one can do the coding, edit it, call datasets, do spatial calculations, visualize the outputs. GEE apps provide an effective and easy way to publish our finished codes with individual URL for public access. With Apps, users can use simple UI elements to access Earth Engine's data catalog and computational power. Anyone can type in the URL and visit a webpage containing the code with the designed UI visible and mapping area; the user simply gives the input and clicks on a button to get the processed output result. The processing is totally handled by GEE running in the background, as the webpage is just a frontend to the codes written in the GEE code editor in the backend. In our case, too, the UI has been designed to be as minimal and user friendly as possible having input boxes with clearly written information on top. Users can interact and input the required data and get an output which can be map data, numbers, graphs, etc. as the coding was done. In the present case, when the user chooses the number of criteria they want to include, input the pairwise comparative values and just click on a button below the UI and the AHP procedure will give the weightage values based on the input, and these will be applied to the number of criteria selected as layers and then that suitability layer will be generated.

A panel was created using *ui.Panel* to hold all the front end elements and then within it messages and texts were displayed using *ui.Label* along with styling options. Next, an input box was provided where the user can provide the link to the .csv asset containing the comparative scoring for all the criteria. The command *ui.Textbox* was used extensively to create the input boxes along with styling options. At the end of the panel, a button is present which, when clicked, calls the AHP function. This function accepts the inputs from the CSV asset provided by the user and further calculations proceed. Here the panels, widgets, input boxes, buttons are all created. Next, GEE gives us functions and commands to create a front end, accept user inputs, make and display buttons that, when clicked, trigger, or call a part of the coding; these were all implemented in this study. Besides these, charts, checkboxes, sliders, and many more options are also available to the user.

3. Analysis Of Ahp Outputs

Kolkata Municipal Corporation handles a maximum of the total MSW generated daily within Kolkata, about 3500-4500 MT/Day. Dhapa disposal ground is located on the fringes of the East Kolkata Wetlands and covers a total area of approximately 35 ha, out of which 12.14 ha is the old dumping ground that is closed off and turned into a green zone. The remaining 23 ha is in use at present for the daily disposal of collected MSW from and around Kolkata (KMC, 2010). This disposal ground at Dhapa is an ecological and environmental hazard (Kim et al., 2010; Matejczyk et al., 2011; Paoli et al., 2012) has long been abolished still underuse (KMC, 2010, WBPCB, 2015). The dumping has led to contaminated water bodies (nearby fisheries), soil (Ali and Ahmed 2019) and affecting the people living in the vicinity of the dump. So even though it is high time to look for viable alternatives and shift to that, in turn, closing this landfill site, KMC is still using it (KMC, 2010).

MSW Landfill suitability within the vicinity of Kolkata city was taken as a case study to find alternative/additional landfill location of Dhapa Landfill. The developed tool in GEE is being used to find the weightage of each layer to calculate the suitability of MSW landfill. The weightage is based on the comparative scores between the different criteria given as input to the tool. In addition, a consistency check has been integrated inside the code, which checks if the user's scores will provide optimized results. All the input layers have been shown in Fig. 4.

3.1. Spatial layers

a) Land Slope

Within the area of interest, away from the river Ganga Highly Suitable to Suitable conditions are commonly observed with occasional marginally suitable conditions. When shifted closer to the river specially near the banks, conditions ranging from unsuitable to marginally suitable are observed, indicating significant changes in the slope of the ground.

b) Population Density

The regions of highly suitable conditions are mainly observed in the north and southeastern parts of the area. Regions of suitable and marginally suitable are mainly seen in the eastern and western parts. All of this primarily suggests that the main central regions and some parts in the north and south are completely unsuitable.

c) Precipitation

The precipitation variation is not very significant within this area; that is why 30-year data has been considered from which the mean value is taken to map the suitability condition. Highly suitable and suitable regions are mostly confined towards the northern end of the area with southern regions having unsuitable conditions.

d) Temperature

Temperature variation throughout the area is not that significant, so 30-year data has been considered from which the mean value is taken. This shows highly suitable and Suitable regions are mostly confined in the eastern region outside the Kolkata ward boundary. Inside the boundary, mostly, unsuitable and conditionally suitable conditions are prevalent.

e) Surface water bodies

As discussed in Table 3, there are buffered regions around the water bodies in the area. Regions denoted by the dotted colour and the first 200m buffer in brown colour are unsuitable. The most preferred region or most suitable are the ones in light pink.

Table 3
Weightage table of the input datasets

Layers/Criteria	Weightage	Reason
<i>Slope</i>	0.15	Almost flat terrain throughout the area of interest. Significant variation is not observed
<i>Population</i>	0.28	Populated regions to be avoided as far as possible. Areas with lower population density or no population need to be chosen.
<i>Precipitation</i>	0.13	Overall precipitation variation is not much observable within the area of interest, so a relatively lower weightage has been given.
<i>Temperature</i>	0.09	Overall temperature variation is not much observable within the area of interest, 1 to 2 degree Celsius at best. So a relatively lower weightage has been given.
<i>Water Bodies</i>	0.11	Excluding areas covered by water and buffering regions around it is necessary so as to avoid wrong suitability and close proximity to such water bodies. The buffers range between 0, 200m, 400m, 600m, 800m and 1000m.
<i>POI</i>	0.09	Same goes for protected zones, monuments, public places and other points of interest within the area interest. The buffer ranges between 200m, 400m, 600m, 800m and greater.
<i>Roads</i>	0.06	Readymade road maps were also not available for free access and which were editable and usable, so this layer was created externally in a GIS software with Google maps as reference as well as OSM basemap, from which the main roads were extracted and the missing roads were filled in. Buffers were created which ranges from 100m to 400m.
<i>Groundwater</i>	0.05	The depth of groundwater is an important aspect so as to not cause contamination due to shallow depth of groundwater in the suitable areas. Regions with the highest water depth are to be chosen as the most suitable.
<i>Geomorphology</i>	0.04	Soil characteristics and geomorphic nature of the suitable areas will dictate a lot of other characteristics and this needs to be addressed with high priority.

f) Protected zones/regions

Similar to water bodies, the protected zones within the area have been buffered around, with regions demarcated by dotted pattern and brown colour (200m) are all unsuitable regions. The region in light pink is the only highly suitable region of choice.

g) Major Roads

Regions in brown are the actual roads; the immediate buffer in the colour red is 100m. Both of these are entirely unsuitable. Similar to above, the light pink colour is the most highly suitable region.

h) Geomorphology

This layer represents the geomorphologic characteristics of the area under consideration. The older levee of the region is the most suitable region with respect to this criterion, and the most unsuitable is the inter-distributary marsh (Nath et al., 2014).

i) Groundwater

This layer represents the distribution of the groundwater in the region. The most highly suitable region may be observed in the southwestern part of the area. This region has the highest groundwater depth, with the lowest being the brown and red areas, making them unsuitable and conditionally suitable.

j) Suitability map

The area of interest or the study area is shaped like the one as seen above due to the geomorphology data, which was limited to that extent. This geomorphology layer data is very accurate at such a small scale as boreholes were used to collect the physical data (Nath et al., 2014). The COPERNICUS LULC layer used in the study is a global dataset. The accuracy required at the regional scale of Kolkata is not present in this dataset and thus some misclassifications may occur. To solve this issue, regional scale LULC is required which will increase the accuracy of the classification.

The overall suitable areas have been firstly chosen from the suitability layer generated by GEE-based AHP framework, where the nine layers are being incorporated based on the comparative scoring into one suitability layer. The area for each class was calculated and has been shown in Table 4. Total Municipal Solid waste, population, waste generation rate and other datasets are being used to calculate a volume. From this area are being calculated using the depths and surface area of such landfills. The surface area can be compared with the patches of the suitability pixels to identify the potential areas. More accuracy can be achieved in pinpointing the exact locations by taking into account the secondary attributes like odour, public acceptability, distance from the current dumping location, etc. Due to the ongoing pandemic situation within the timeline of this study, physical data collection or collection of ground truths could not be carried out. To mitigate this, Google Earth, Google Maps, Street view were implemented as a reference and validation procedure, as seen above. The street view images are collected from Google maps itself, which are user-submitted images of the area within close vicinity to the selected suitable sites as specified above. This type of validation is quite unique and accurate in its approach as a real view of the concerned area can be observed in aerial view and as images geotagged to that area.

Table 4
Area statistics of the suitable areas

Suitability Class	Area (sq. km.)	% Area
Marginally Suitable	10.84	43.12
Moderately Suitable	9.86	39.22
Highly Suitable	4.44	17.66

3.2. Importance of GEE and AHP and their combination

AHP as MCDM process helps calculate the weightage values for each criterion based on the pairwise comparative values from the user. The same procedure has been implemented in the GEE environment. Previously no such functions or commands were integrated within GEE. This helps us calculate the weightage criteria for each of the layers like slope, population, land use, precipitation, etc., according to the comparative pairwise value from the user as input. This helps us determine which layer gets what kind of importance and ultimately affects the site selection. So AHP within GEE enables us to use the GEE dataset repository with other GEE assets to generate a landfill site suitability over Kolkata and its surroundings using the calculated criteria weights from the AHP process. It's a one-stop application for weightage calculation and mapping the suitable layer on-fly for various applications.

AHP integration or the use of AHP to assess layers' weightage and prepare a suitability map is nothing new. However, it was not implemented in GEE earlier. Earlier in the studies (Acharya et al., 2019, Peter et al., 2020, Swain et al., 2020; Yalaw et al., 2016), where AHP was used to assess suitability, AHP was done externally on some other platform and then those coefficients were given as inputs to the code. But the fact that the present tool is dynamic in nature makes it more future-forward as it can accept user inputs and works accordingly seamlessly. The AHP calculation and mapping integration is dynamic and works right from the start where the user inputs the pairwise comparative scores directly into the code panel as input and the coefficients, integration into each layer, and the final suitability map all happens on the fly with the click of a button. This makes the code applicable for site suitability and various other decision-making cases natively within GEE.

The calculations made by AHP are simple and always follow the decision maker's choices and inputs. The tool can thus be used to translate the decisions and choices made by the decision-maker into a multi-criteria ranking (Marcomini et al., 2009). On the other hand, AHP may require the user to make many decisions, especially for problems with many criteria. The number of pairwise comparative scores grow quadratically with the increase in the number of criteria. The developed tool is flexible to increase the input layers and correspond pairwise comparison values with some customization in the code.

The *Run with profiler* option in GEE code editor provides the information about different computation time and memory usage of different sections of the code like *reduceRegion*, loading assets, Array

computations etc. On average, 0.032 sec CPU time and peak memory consumption of 337k is initially observed while all the resources are loaded, algorithms are called, and the assets finish loading. Once the user provides all the necessary inputs or decides to run with the default values, click the button in the UI to start the AHP and layering process, the code begins its processing. Overall this shows that the code is optimized and quick to run even if it is handling a lot of data, calculations and resources; even the memory consumption is under check as GEE limits the amount of memory bandwidth each user gets.

4. Conclusions

In the present study, the computation power of GEE has been harnessed to implement AHP, a method of MCDM, which is used to acquire alternative solutions to problems having multi-dimensions and criteria. AHP, although being an established method, was not developed in GEE. The most exciting and important factor is that this tool can be used for many AHP-based applications. These cases can be varied, but if it involves multiple criteria and decision making is required, this code will handle it with ease, with space to add more criteria and change region, making it ideal for MCDM approaches. The whole process of giving weightage to each layer depends on the user's pairwise comparative values. These comparative values will vary from user to user or application to application. The tool provides the opportunity to upload pairwise comparison values as CSV format. Site Suitability analysis of Dhapa Landfill of KMC has been considered as an example for the case study. However, the code can be used for other suitability analysis for other areas and not limited to the use case presented here.

Declarations

Competing interests

The authors declare no competing interests.

Data availability statement

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request. However, most of the datasets are available publicly in Google Earth Engine data catalog.

References

Acharya, P., Biradar, C., Louhaichi, M., Ghosh, S., Hassan, S., Moyo, H. and Sarker, A. (2019). Finding a Suitable Niche for Cultivating Cactus Pear (*Opuntia ficus-indica*) as an Integrated Crop in Resilient Dryland Agroecosystems of India, *Sustainability*, 11(21), p.5897.

Alanbari, M.A., Al-Ansari, N., Jasim, H. K., and Knutsson, S., Qadaa, Al-M. (2014). Landfill Site Selection Using GIS and Multicriteria Decision Analysis, *Engineering*, vol. 06, no. 09, pp. 526-549.

- Ali, A S.K., and Ahmad A. (2019). Analysis of Chemical and Heavy Metal Concentrations of Leachates and Impact on Groundwater Quality Near Dhapa Dumping Ground, Kolkata, *Asian Profile, Vol. 47, No. 1*.
- Ali, A S.K., and Ahmad A. (2020). Suitability analysis for municipal landfill site selection using fuzzy analytical hierarchy process and geospatial technique, *Environmental Earth Science, 79:227*
<https://doi.org/10.1007/s12665-020-08970-z>
- Alkaradaghi, K., Ali, S.S, Nadhir, A.A, Laue, J., and Chabuk, A. (2019). Landfill Site Selection Using MCDM Methods and GIS in the Sulaimaniyah Governorate, Iraq, *Environmental Behaviour and Collective Decision Making*, <https://doi.org?10.3390/su11174530>.
- Amani, M, Ghorbanian, A., Ali, S.A., Mohammad K. (2020). Google Earth Engine Cloud Computing Platform for Remote Sensing Big Data Applications: A Comprehensive Review, *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*. DOI: 10.1109/JSTARS.2020.3021052.
- Center for International Earth Science Information Network - CIESIN - Columbia University. (2018). Gridded Population of the World, Version 4 (GPWv4): Population Density, Revision 11. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). <https://doi.org/10.7927/H49C6VHW>.
- Chabuk, J.A., Al-Ansari, N., Hussain, M.H., Knutsson, S., Pusch, R. (2017). GISbased assessment of combined AHP and SAW methods for selecting suitable sites for landfill in Al-Musayiab Qadhaa, Babylon, Iraq, *Environmental Earth Sciences*, Article 209.
- Fuentes, I., Padarian, J., Ogtrop, F.V., and Vervoort, R.W. (2019). Comparison of surface water volume estimation methodologies that couple surface reflectance data and digital terrain models, *Water, vol. 11, no. 4, Art. no. 780*.
- Funk, C., Pete, P., Martin, L., Diego, P., James, V., Shraddhanand, S., Gregory, H., James, R., Laura, H., Andrew, H., and Joel, M. (2015). The climate hazards infrared precipitation with stations—a new environmental record for monitoring extremes. *Scientific Data 2, 150066*. doi:10.1038/sdata.2015.66 .
- Gorelick, N., Hancher, M., Dixon, M., Ilyushchenko, S., Thau, D., and Moore, R. (2017). Google earth engine: Planetary-scale geospatial analysis for everyone, *Remote Sens. Environ., vol. 202, pp. 18–27*.
- Kaur, J, and Shekhar, C. (2020). Multimodal medical image fusion using deep learning. *Advances in Computational Techniques for Biomedical Image Analysis*. <https://doi.org/10.1016/B978-0-12-820024-7.00002-5>.
- Khan, A.S., Chaabane, A., and Dweiri, T.F. (2018). Multi-Criteria Decision-Making Methods Application in Systematic Literature Review, *Multi-Criteria Methods and Techniques Applied to Supply Chain Management*, doi: 10.5772/intechopen.74067
- Kim, K.R., and Owens, G. (2010). Potential for enhanced phytoremediation of landfills using biosolids—a review. *Journal of Environmental Management, 91(4): 791–797*

- KMC. (2010). *Methane to Market: Assessment report*. https://www.globalmethane.org/Data/1128_Dhapa.Assessment.Report.4-27-10.pdf.
- Kumar, L., and Mutanga, O. (2018). Google Earth Engine applications since inception: Usage, trends, and potential, *Remote Sens.*, vol. 10, no. 10, Art. no. 1509.
- Marcomini A, Suter II GW, Critto A. (2008). Decision support systems for risk-based management of contaminated sites. *Springer Science & Business Media*
- Matejczyk, M., Paza, G.A., Naęcz-Jawecki, G., Ulfing, K., Markowska-Szczupak, A. (2011). Estimation of the environmental risk posed by landfills using chemical, microbiological and ecotoxicological testing of leachates. *Chemosphere*, 82(7): 1017–1023
- Nath, S.K., Adhikar, M.D., Maiti, S.K., Devaraj, N., Srivastava, N., Mohapatra, L.D. (2014). Earthquake scenario in West Bengal with emphasis on seismic hazard microzonation of the city of Kolkata, India. *Natural Hazards and Earth System Sciences*. 14(9):2549-75.
- Paoli, L., Corsini, A., Bigagli, V., Vannini, J., Bruscoli, C., Loppi, S. (2012). Long-term biological monitoring of environmental quality around a solid waste landfill assessed with lichens. *Environmental Pollution*, 161: 70–75
- Peter, B.G., Messina, J.P., Lin, Z., and Snapp, S.S. (2020). Crop climate suitability mapping on the cloud: a geovisualization application for sustainable agriculture. *Scientific Reports*, 10(1), pp.1-17.
- Ravanelli, R. (2018), Monitoring the impact of land cover change on surface urban heat island through Google Earth Engine: Proposal of a global methodology, first applications and problems, *Remote Sens.*, vol. 10, no. 9, Art. no. 1488.
- Saaty, T.L. (1980). *The Analytic Hierarchy Process*. McGraw-Hill, New York.
- Swain, K.C., Singha, C. and Nayak, L. (2020). Flood susceptibility mapping through the GIS-AHP technique using the cloud. *ISPRS International Journal of Geo-Information*, 9(12), p.720.
- Wang, L., Yan J., and Ma, Y. (2019). *Cloud Computing in Remote Sensing*. Chapman and Hall/CRC ISBN: 978-1138594562. DOI: 10.1201/9780429488764.
- WBPCB. (2015). Environmental and social management plan for containment of Dhapa Dumpsite Final Report.
- Yang, Z., Li, W., Chen, Q., Wu, S., Liu, S., and Gong, J. (2019). A scalable cyberinfrastructure and cloud computing platform for forest above ground biomass estimation based on the Google Earth Engine, *Int. J. Digit. Earth*, vol. 12, no. 9, pp. 995–1012.

Figures

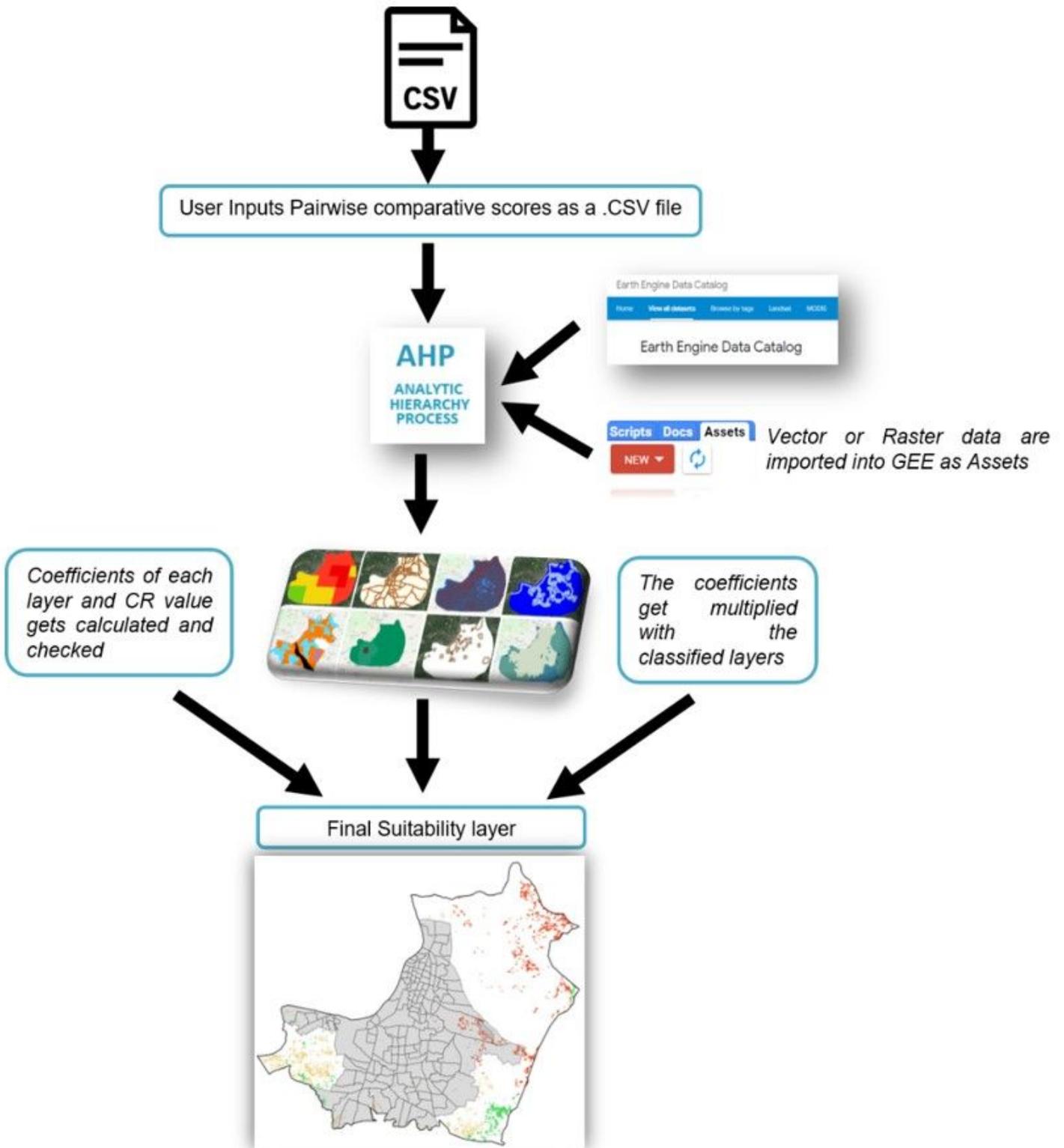


Figure 1

Overall workflow

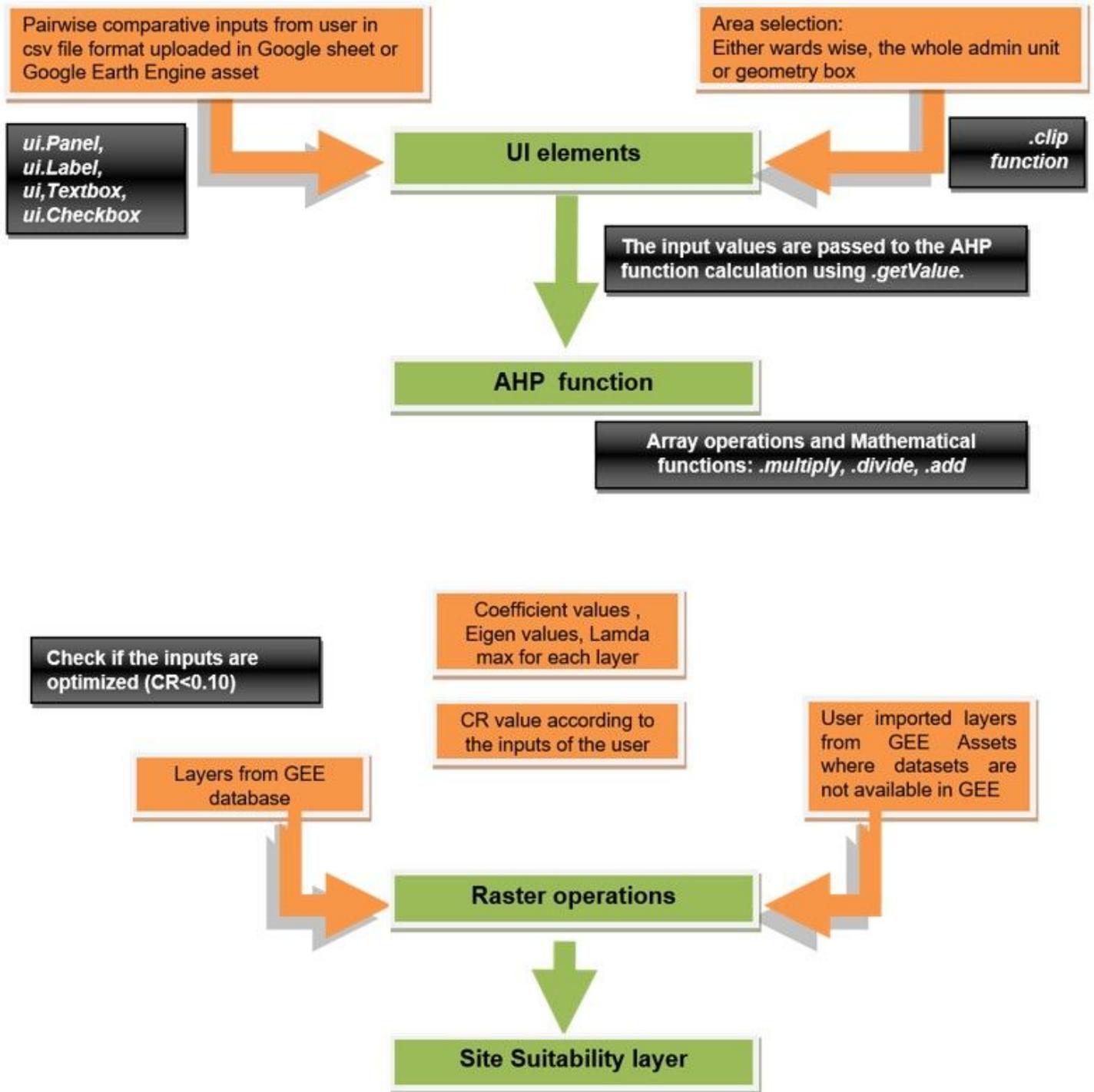


Figure 2

Functional workflow of the AHP algorithm in GEE



Figure 3

Location of the landfill (source: Google Earth)

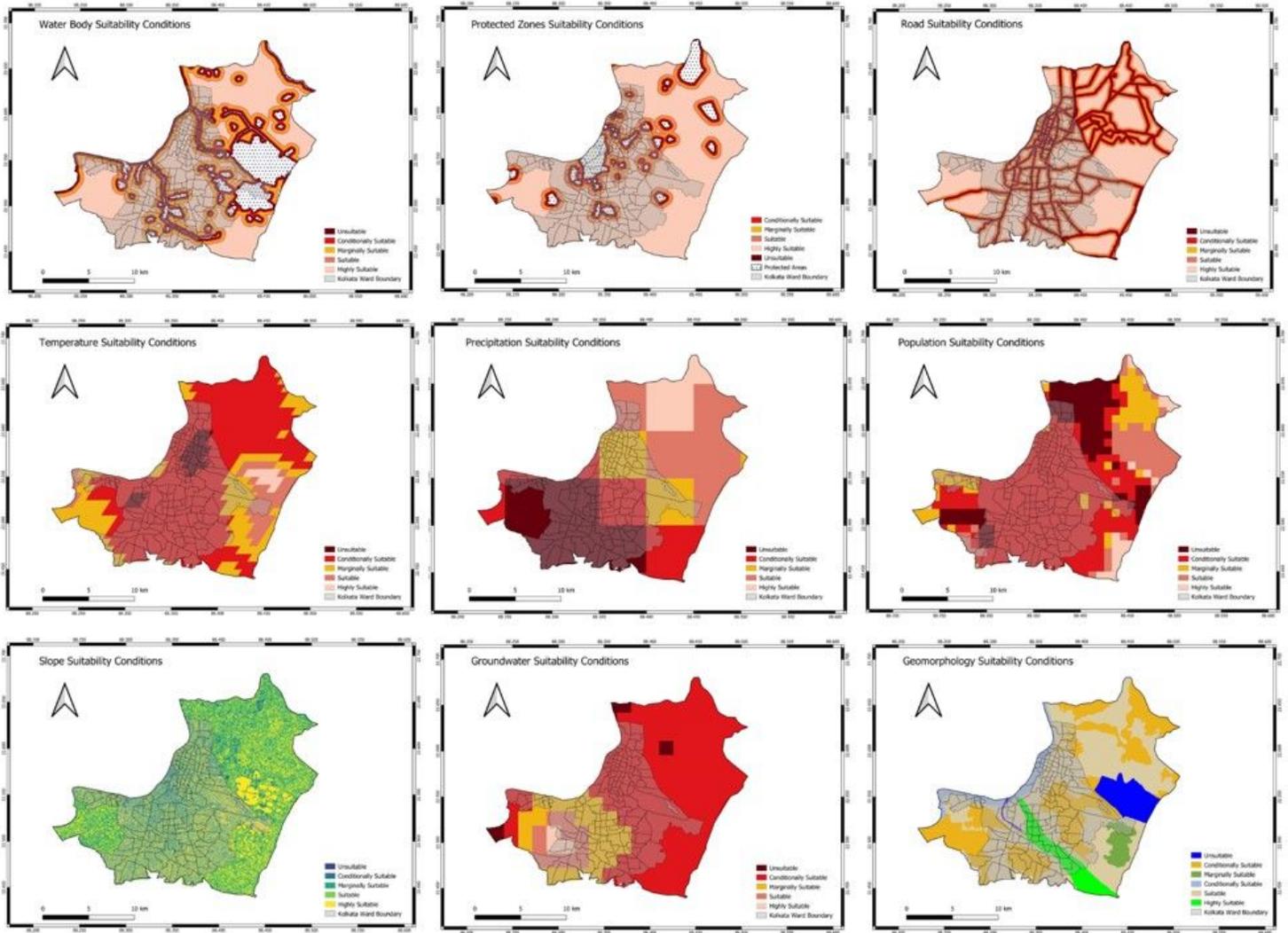


Figure 4

Input layers

Suitability Conditions after Classification

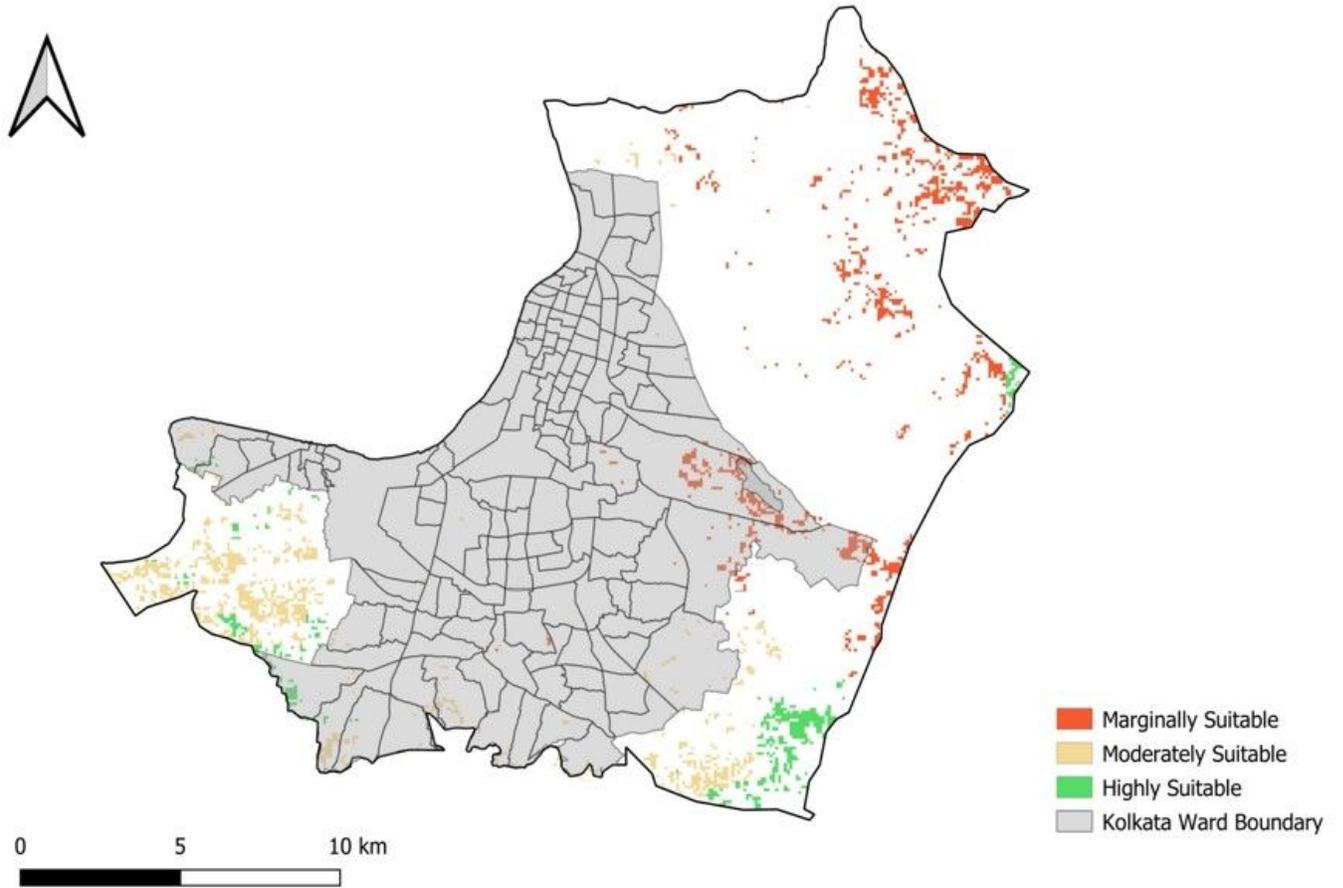


Figure 5

Suitability Layer

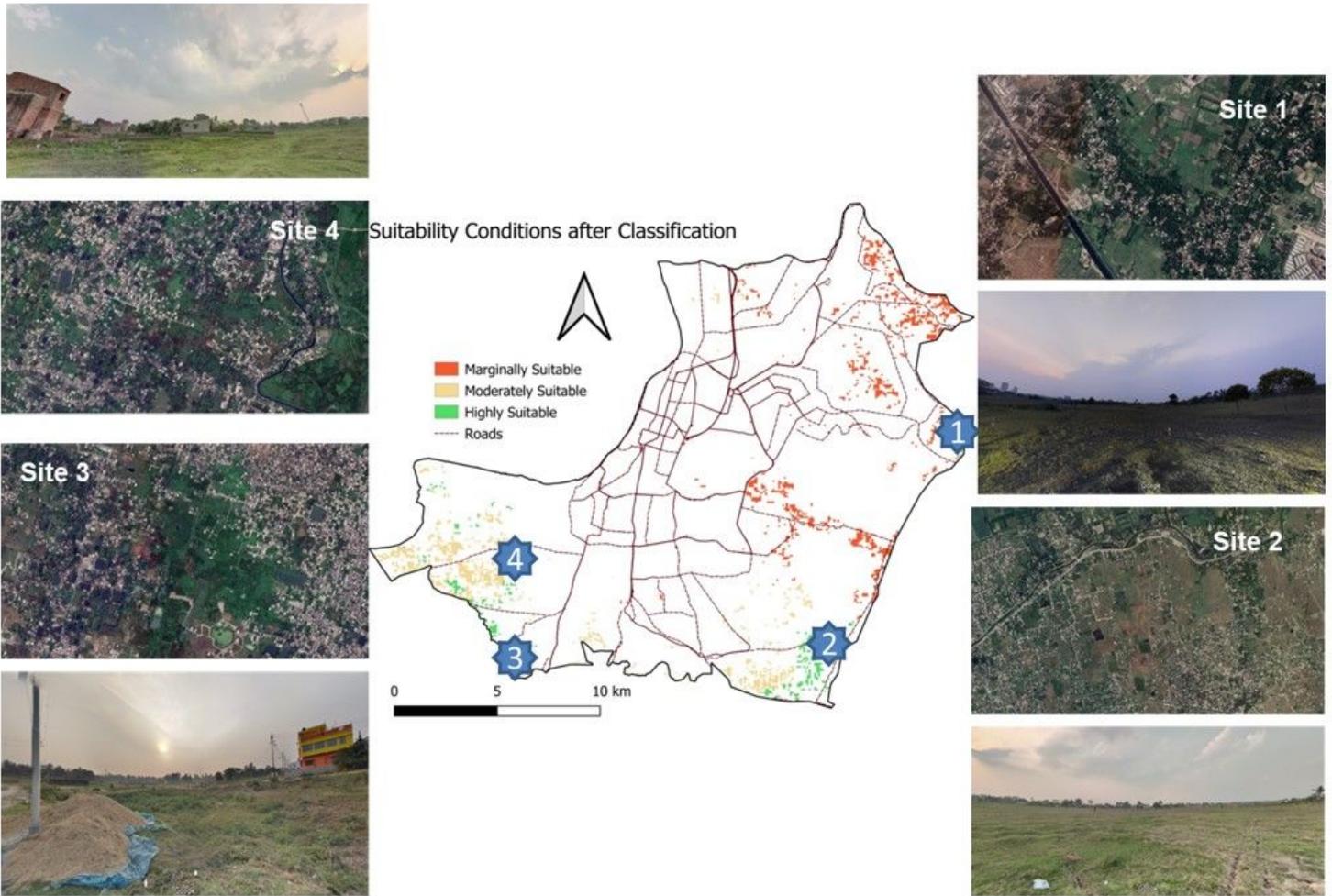


Figure 6

Validation through Google Street View

AHP based Landfill Site Suitability Mapping
A geovisualization tool for identifying suitable landfill areas

Enter the attributes below

Enter the number of attributes in the CSV file
Attributes, Defaults to 9

After uploading CSV asset in GEE, provide below details
CSV Template : shorturl.at/mBHJ9

Enter criteria asset ID

Enter subcriteria asset ID

Enter the criteria names

Criteria 1 Criteria 2 Criteria 3 Criteria 4 Criteria 5
Criteria 6 Criteria 7 Criteria 8 Criteria 9

Tick to see ward wise (select from below)

99

Tick to download suitability layer

Figure 7

UI of AHP tool