



Suitable sites for fog water collection in Cape Town, South Africa

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Abstract

The worldwide shortage of fresh water is a critical issue, with two-thirds of the world's freshwater being inaccessible, as it is locked up in frozen glaciers. Additionally, arid areas such as South Africa are experiencing increased water scarcity, with regions such as Cape Town having already announced “day zero”, the day when the city's dams will run out of water. Fog water collection provides a sustainable and alternative source of fresh water. Nevertheless, existing methods for identifying suitable locations rely on manual and trial-based approaches. This study focuses on finding suitable locations for fog harvesting in Cape Town via geographic information system (GIS)-based multicriteria decision analysis. To accomplish this, relevant factors for fog harvesting were identified in the literature and then transformed into spatial data layers. Next, weights were assigned to criteria layers via the analytical hierarchy process method, ultimately creating a final suitability map through a weighted overlay of these criteria layers. The findings of this study indicated that regions near coastlines, with low temperatures and strong winds, elevations above 1000 m or below 200 m, and steep slopes facing the ocean are the most favourable locations for harvesting fog water. This approach could be replicated in other regions, but caution is necessary when determining criteria and thresholds because of the localised nature of fog.

Keywords Fog harvesting · Site suitability · Water security

Introduction

Goal 6 of the United Nations Sustainable Development Goals aims to ensure universal access to clean water and sanitation, as well as promote the conservation and replenishment of water ecosystems (United Nations 2015). Additionally, sustainable water resources are crucial for improving household livelihoods and driving economic development. It is particularly critical in developing countries located in arid and semiarid regions (e.g., South Africa), which are most affected by limited freshwater supplies (Fessehaye et al. 2014).

Fog water collection has proven to be an alternative and sustainable source of fresh water that can help mitigate the shortages of fresh water in arid regions (Qu et al. 2013). A pilot fog harvesting project implemented in a region in Southwest Morocco in 2013 demonstrated that fog harvesting could yield an annual average of 2.3 million litres of

water in the region's current climate (Dodson and Bargach 2015). The UN Climate Technology Centre and Network defined fog harvesting as an alternate technique that is used to trap water droplets found in fog. This technique involves collecting moisture from fog via specialised mesh nets or structures, which capture the water droplets as they pass through the fog (CTCN 2017). The collected water is suitable for human and animal consumption as well as for use in subsistence agriculture (Castelli et al. 2023).

The practice of fog harvesting has no documented origins, but scientific interest began in the early 1900s. One of the earliest documented experiments took place in South Africa in 1901. Despite over a century of research, significant progress has only been notable in recent decades (Qadir et al. 2021). Sustainable fog harvesting goes beyond just identifying areas that could benefit from alternative water resources; it is crucial to select suitable sites that can yield sufficient quantities of water (Qadir et al. 2021). As illustrated in the available literature, certain conditions are used to measure the sustainability of fog harvesting in an area. According to Gandhidasan et al. (2018), areas with high humidity, high wind speeds and low temperatures were

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found to be optimal for high-frequency and persistent fog episodes.

In contrast, Fessehaye et al. (2014) reported that high mountain ranges, steep slopes, and proximity to the coast are crucial factors supporting fog harvesting. High-elevation areas are desirable for fog harvesting. However, a study on the largely flat west coast of South Africa revealed that regions with elevations of less than 200 m had the highest fog water yield potential within a 15 km proximity to the coastline (Olivier et al. 2015).

In 2012, Klemm et al. (2012) conducted a review searching for all documented fog harvesting projects in the last 50 years. The study revealed (Fig. 1) that most projects were implemented in coastal countries classified as semiarid to arid regions with very little rainfall.

Fessehaye et al. (2014) conducted a similar study on the global collection of fog harvesting projects, reporting their locations, operational years, and purposes. These projects were predominantly situated in dry tropical and subtropical regions. Several fog harvesting projects and pilots have been implemented both globally and locally. Typically, researchers identify water-stressed communities and assess nearby fog-prone areas. They usually conduct a pilot study with a small-scale fog collection system to test the feasibility of larger-scale projects by quantifying the potential water yield.

Another study on fog harvesting feasibility conducted by Karimidastenaei et al. (2020) utilised artificial neural network (ANN) algorithms and the analytic hierarchy process (AHP) to identify fog harvesting sites in the Vazroud Watershed, Iran. The researchers collected samples from 100 fog-prone zones and divided these sample points into training and validation datasets. They then identified environmental predictor variables and social predictor variables to assess fog suitability. By multiplying the mathematical calculation of the fog probability with the fog suitability, they

determined the potential for a site's fog harvesting capability index. The AHP was subsequently applied to identify suitable sites; however, this approach is costly because of its extensive field data collection requirements.

Consequently, the current methods for assessing the feasibility of fog harvesting in an area are time-consuming and expensive. Therefore, this study uses geographical information system (GIS)-based multicriteria decision analysis (MCDA) to streamline the identification process of suitable sites for fog harvesting. To achieve this, the relevant factors that support fog harvesting were converted into spatial data layers and assigned weights, ultimately creating a final suitability map through a weighted overlay of these criteria layers. This approach is efficient, eliminates the need for field visits, and proves to be cost-effective.

Materials and methods

The research plan (Fig. 2) consisted of three phases: data collection, data processing, and data analysis. During the data collection phase, an extensive literature review was conducted to identify the factors and constraints required for the suitability analysis, as presented in Table 2. These factors represent opportunities, whereas the constraints denote site limitations. Once the criteria were identified, secondary data were collected. In the second phase, this information was transformed into spatial datasets to represent both factors and constraints visually. Finally, an AHP was used to assign weights based on the importance gathered from the literature to rank the criteria through pairwise comparisons. Creating a weighted overlay ('Weighted Sum') generated a suitability map using these factors; subsequently, the constraint map served as a mask for removing unsuitable areas.



Fig. 1 Map showing the locations of documented fog harvesting projects as of 2012, dating back 50 years (Klemm et al. 2012)

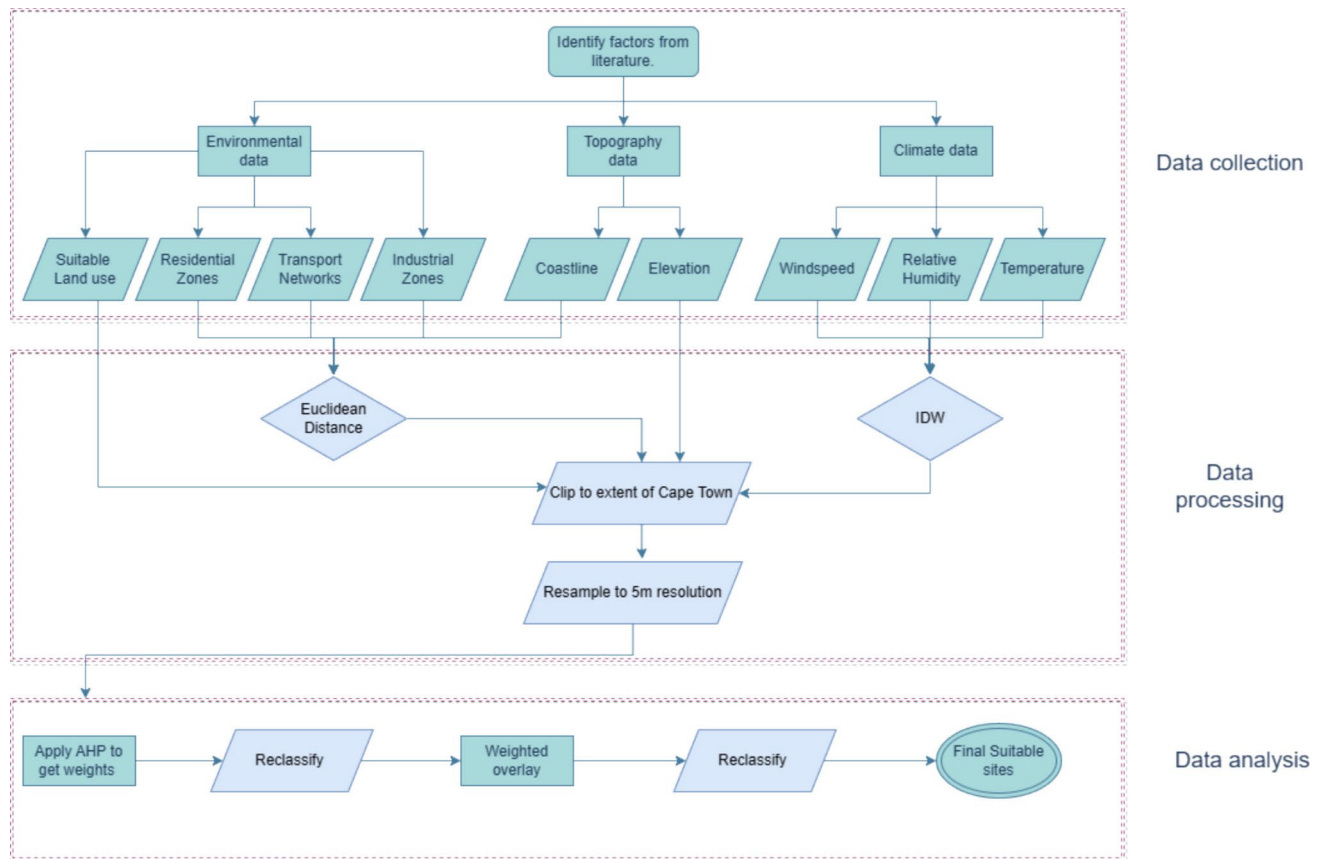


Fig. 2 Workflow diagram of the study design

Study area and data sources

The city of Cape Town is home to the iconic table mountain and is one of the eight metropolitan municipalities in South Africa. It is located between latitudes 33.45° S to 33.36° S and longitudes 18.28° E to 19.01° E and is situated in the southwestern region of the country, with a surface area of approximately 2440 km^2 (Treasury 2012). The city features a 307 km coastline along the South Atlantic Ocean and rivers spanning approximately 1900 km. It has a warm Mediterranean climate, with moderately wet winters from May–October and dry summers from December–March, making it one of the most arid regions in South Africa. The Western Cape Government has forecasted a 30% reduction in rainfall by 2030 due to accelerated climate change. From 2015 to 2018, Cape Town faced its most severe drought on record, leading to an increase in the number of people with limited or no access to water (Cole et al. 2021) (Fig. 3).

An investigation of the factors that contribute to fog harvesting was carried out, followed by the identification of the necessary data to represent these factors. Published secondary data that are freely available were gathered and utilised. First, climatological data were obtained from the Open-Meteo API on the basis of ERA5 reanalysis data.

Open-Meteo provides only climatological data for coordinates of points of interest; as such, some evenly distributed random points were generated within the study area (Fig. 4), and climatological data for the period of 01/01/2015–31/12/2020 were downloaded using their coordinates. The sampled points were later interpolated via inverse distance weighting (IDW) to cover the study area, as further described in Sect. “Climatic data processing”. The parameters for the data were as follows:

- Temperature—air temperature at 2 m above the ground
- Windspeed—wind speed at 10 m above the ground

Second, a five-meter digital elevation model was sourced from the city of Cape Town (CoCT). This was then used to generate the aspect and slope maps. Finally, we downloaded the South African national land use and land cover dataset (30 m) from the Department of Forestry, Fisheries, and the Environment open portal. This comprehensive dataset covers various land uses in South Africa, including built-up areas, cultivated lands, and water bodies. This approach is used to extract features such as industrial zones, transportation networks, and residential areas, which are crucial for identifying unsuitable locations for fog harvesting. Table 1

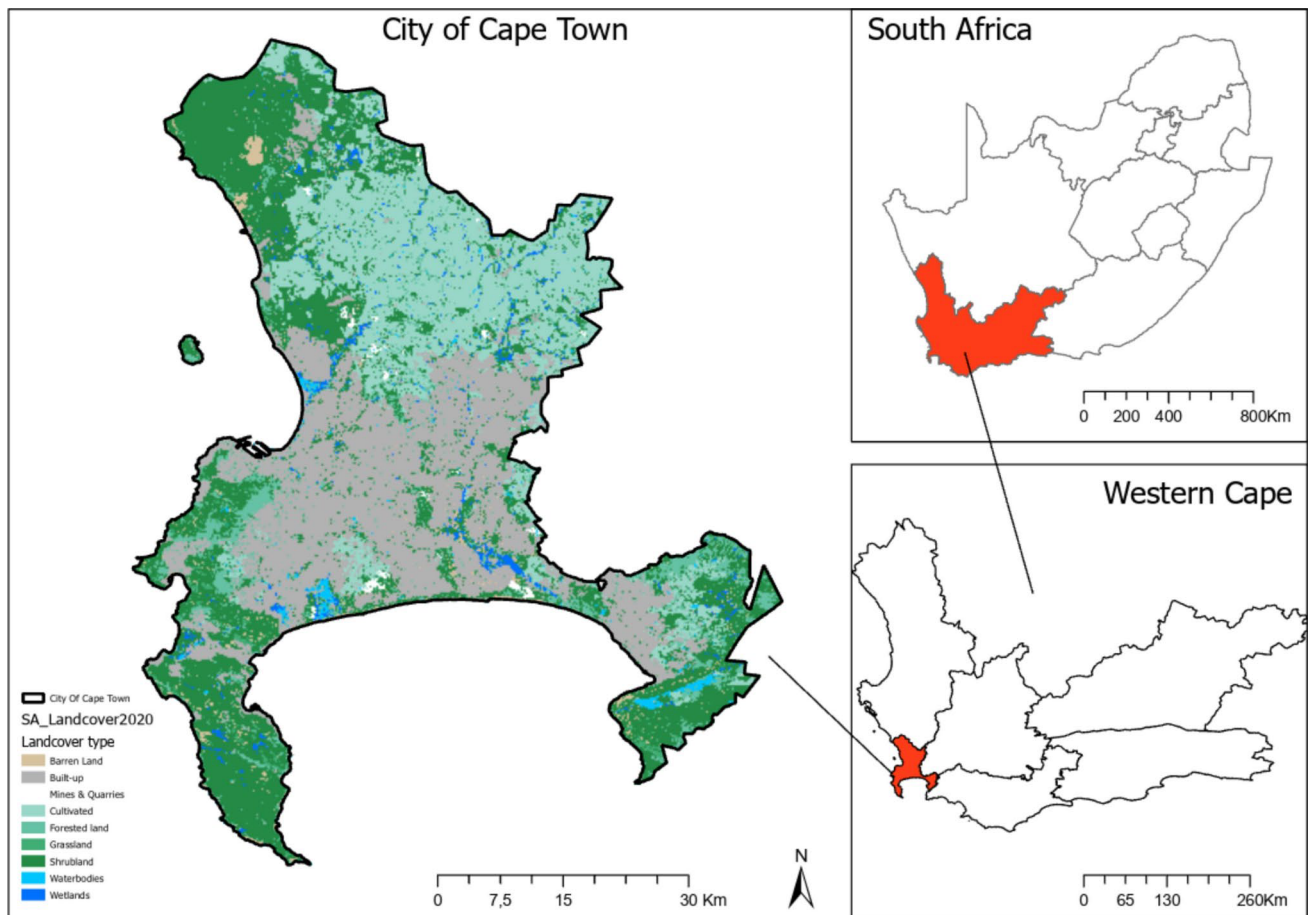


Fig. 3 Map of the study area

summarises the data, their providers, and the derived spatial layers.

Criteria determination

Site selection for fog harvesting depends on understanding the process of fog formation and other factors that impact its feasibility. Fog results from the climatic and topographic composition of a region, so it is important to consider local studies to ensure that the proper criteria are selected. The Water Research Commission funded various projects across South Africa to identify the factors supporting fog formation and fog harvesting in this study (Louw et al. 1998; Olivier 2002, 2004; Olivier and De Rautenbach 2002; Olivier and Van Heerden 2003; Olivier et al. 2015). Three categories of data were collected: climatic, topographic, and environmental. These datasets are summarised in Table 2 along with the extracted features that constitute the study's criteria, and this is the first stage (data collection) of the study design.

Converting factors to spatial data

The second stage of the study design involved converting the dataset collected in Sect. “Criteria determination” to spatial data layers and harmonising it to the same format, scale, and resolution. An overview of the steps is presented in Fig. 5.

Climatic data processing

The inverse distance weighting (IDW) technique was used to interpolate the fifteen data points obtained from the Open-Meteo API. This technique is commonly employed for interpolating climate data across unknown areas. IDW assumes that each measured point has a local influence that decreases as the distance increases. It assigns greater weights to the points closest to the prediction location, with their weights diminishing in relation to the distance (ESRI 2024). The estimated value (z) at location (x) is determined by a weighted mean of nearby observations (Hartmann et al. 2023). Using this technique, the sampled temperature and wind speed data were converted to a raster layer at a resolution of 5 m.

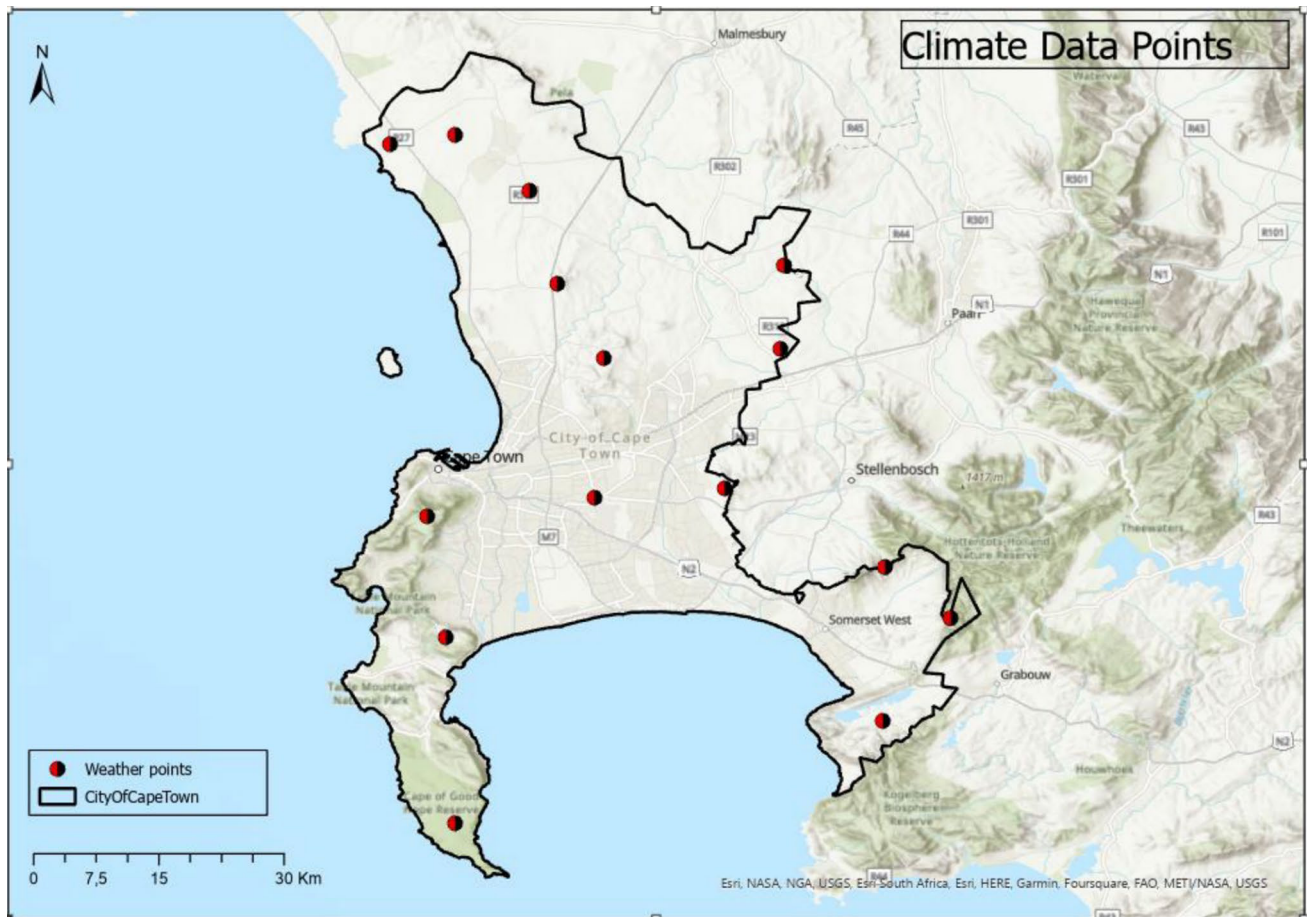


Fig. 4 Locations of the sample points where the Open-Meteo data were collected

Table 1 Summary of the secondary data used, the data source and the resulting layers

Data	Source	Data layers to be derived
Open-Meteo	https://open-meteo.com	Annual data from 2015 – 2020: Mean annual rainfall Mean annual wind speeds Mean annual temperature Mean annual relative humidity
5 m DEM	https://odp-cctegis.opendata.arcgis.com/	Elevation Aspect Slope
30 m Land use/ Land cover	DFFE https://egis.environment.gov.za/gis_data_downloads	Industrial areas Residential areas Transport networks Suitable land cover types Coastline

$$\hat{z}(x) = \frac{\sum_i^n w_i z_i}{\sum_i^n w_i} \tag{1}$$

where

$$w_i = |x - x_i|^{-\beta} \tag{2}$$

Topographic data processing

Using high-resolution elevation data for the study area, the aspect and slope surfaces were calculated, and an ‘Extract by Attribute’ geoprocessing tool was used to extract coastline data from the land use/land cover dataset.

Environmental data processing

The ‘Extract by Attribute’ geoprocessing tool was utilised to extract the industrial areas, residential areas, and transportation layers from the land use/land cover dataset, as shown in Figs. 6 and 7. The Euclidean distance tool was subsequently used to calculate the proximity around these layers

Table 2 Key factors and constraints for identifying suitable sites for fog water collection

Criteria	Type	Description	Literature sources
<i>Climate</i>			
Mean annual temperature	Factor	Fog is most common in the early morning and late evening when surface temperatures are at their lowest. Advection fog occurs when warm air cools and condenses due to the low surface temperature	(Carvajal et al. 2022; Gandhidasan et al. 2018; Olivier et al. 2015)
Mean annual wind speed	Factor	Fog is driven by wind, whether it forms over the sea and is carried inland or when warm air is driven by wind to cooler temperatures where it condenses as radiative fog. Moderate wind speeds are desirable for fog harvesting as extremely high winds can cause the fog to dissipate more quickly	(Gandhidasan et al. 2018; Olivier 2002)
<i>Topography</i>			
Elevation	Factor	Higher altitudes generally experience lower surface temperatures, making them more susceptible to orographic fog. Given that fog harvesting (FH) systems do not require energy to pump water, locating FH sites at high elevations allows for the efficient distribution of water to users. These areas also tend to have air with the highest liquid content	(Batisha 2015; Fessehaye et al. 2014; Olivier et al. 2015)
Aspect	Factor	Orographic fog, especially on the West Coast, is driven by winds coming from the coastline. The terrain should be oriented to face the moisture-laden winds blowing in from the ocean	(Castelli et al. 2023; Hůnová et al. 2021; Olivier et al. 2015)
Slope	Factor	The steep slopes facing the ocean quickly push the moisture-bearing air uphill, leading to an extended cooling period and resulting in orographic or valley fog formation	(Castelli et al. 2023; Fessehaye et al. 2014; Hůnová et al. 2021)
Coast	Factor	Advective fog typically forms over oceans and is then carried inland by the wind. Therefore, proximity to coastlines is another crucial factor to consider when selecting a site for fog harvesting	(Carvajal et al. 2022; Cereceda et al. 2002; Olivier et al. 2015)
<i>Environmental</i>			
Residential	Factor	The most suitable sites should be within 15 km of residential areas to minimise the costs of transporting water to households. These areas include formal residential zones, informal settlements, villages, and small holdings	(Dodson and Bargach 2015; Olivier 2002)
Transportation	Factor	Sites should be located within 4 km of transportation routes to ensure easy access during construction and operation phases. This includes all modes of transport, such as roads and rail networks	(Olivier et al. 2015)
Industrial	Constraint	Fog harvesting sites should be located at least 2 km away from industrial areas to prevent contamination of the fog by air pollutants. These industrial areas include mines and waste dump sites	(Fessehaye et al. 2014; Olivier et al. 2015)
Land cover	Constraint	Certain land cover types, such as built-up areas, water bodies, and forested land, are excluded from suitable sites	(Hůnová et al. 2021; Olivier et al. 2015)

on the basis of each criterion threshold and convert them into raster layers. The Euclidean distance method calculates the distance of each cell in a raster to the closest object of interest (Maria et al. 2020). This creates buffer zones around the features being analysed.

Criteria layer harmonisation

All the layers created in Sects. “[Climatic data processing](#)” and “[Environmental data processin](#)” were in raster format, but they had varying resolutions and scales and covered

Fig. 5 Flow chart showing the steps involved in converting the criteria to the spatial data layer

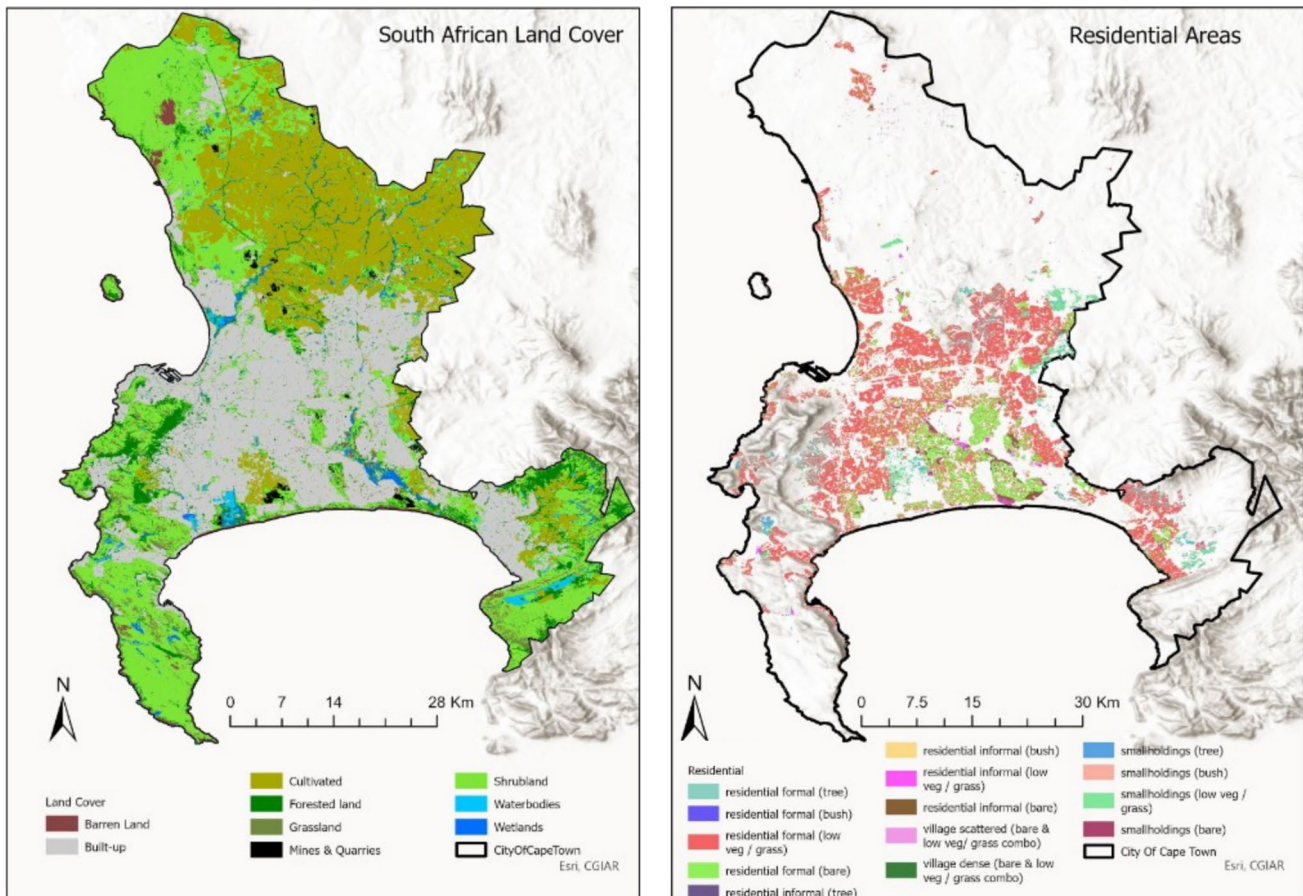
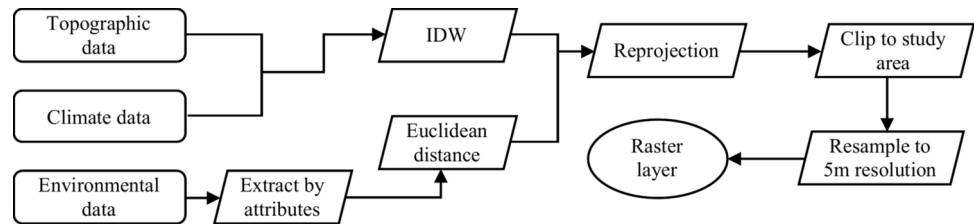


Fig. 6 Map showing the land use/land cover dataset and the residential areas

different spatial extents. The first step in harmonising the criteria layers was to clip them to the same spatial extent using the city of Cape Town boundary, ensuring that analyses were restricted to the study area. Next, the layers needed to be resampled to the same spatial resolution (5 m) to align with the interpolated surfaces. It is essential for all layers to have consistent spatial resolution and projection so that raster cells are correctly aligned for overlay analysis across the criteria layers.

Finally, the criteria layers were standardised to the same scale of values by reclassifying the raster cell values for each criterion to a standard scale. The reclassification was based on discussions from the literature that highlighted the thresholds for each factor (Batisha 2015; Carvajal et al. 2022; Castelli et al. 2023; Olivier et al. 2015). The classes

were grouped into four categories: 0=unsuitable conditions, 1=less suitable conditions, 2=suitable conditions, and 3=most suitable conditions.

Weight assignment and combination

The third stage of the study design involved assigning weights to each criterion on the basis of their perceived importance. This was achieved via an analytical hierarchy process, a robust method used for comparing criteria against each other on the basis of their predictive importance. The weighted sum geoprocessing tool was then employed to combine the criteria.

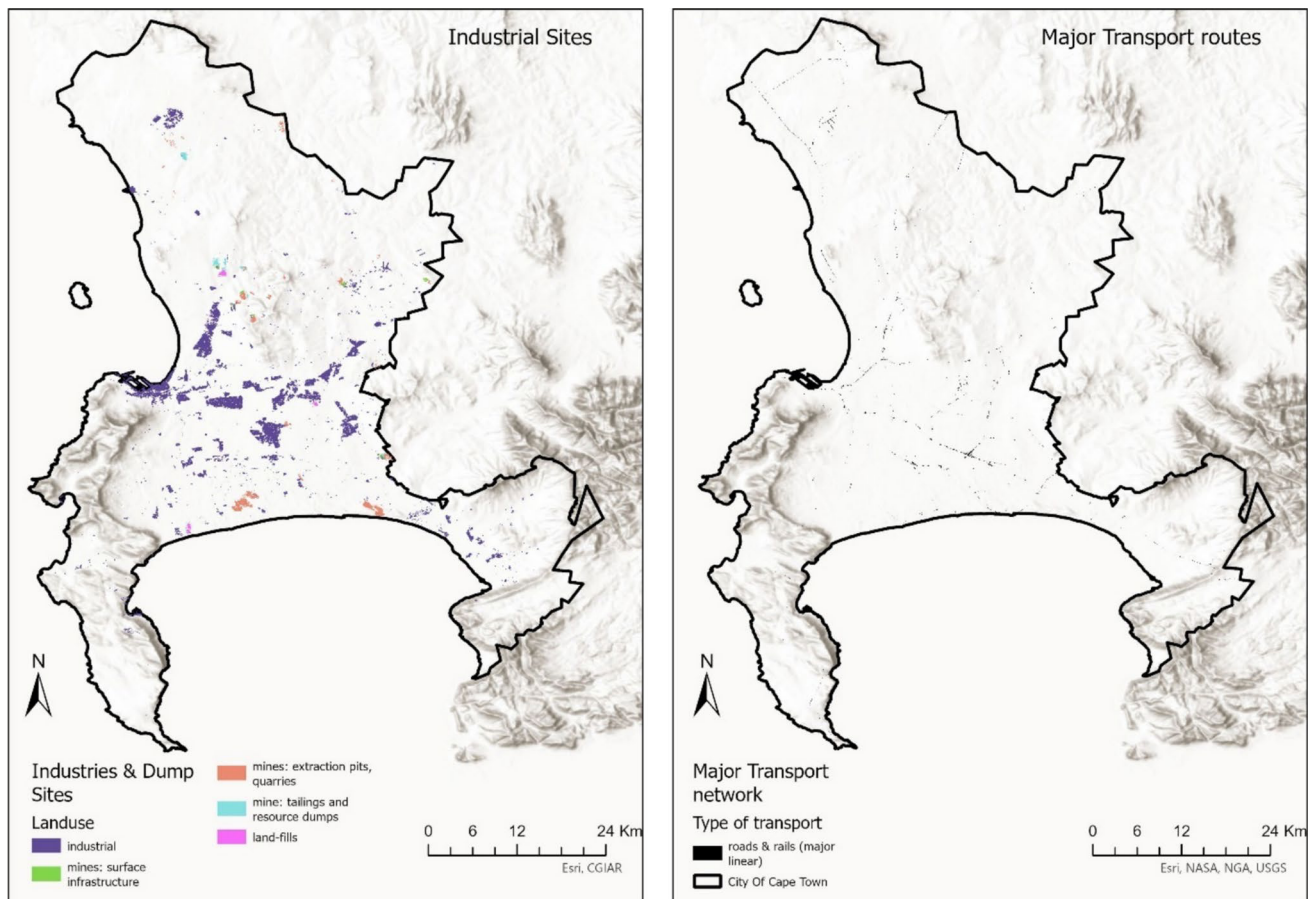


Fig. 7 Map showing the industrial areas and the major transport routes

The analytical hierarchy process (AHP)

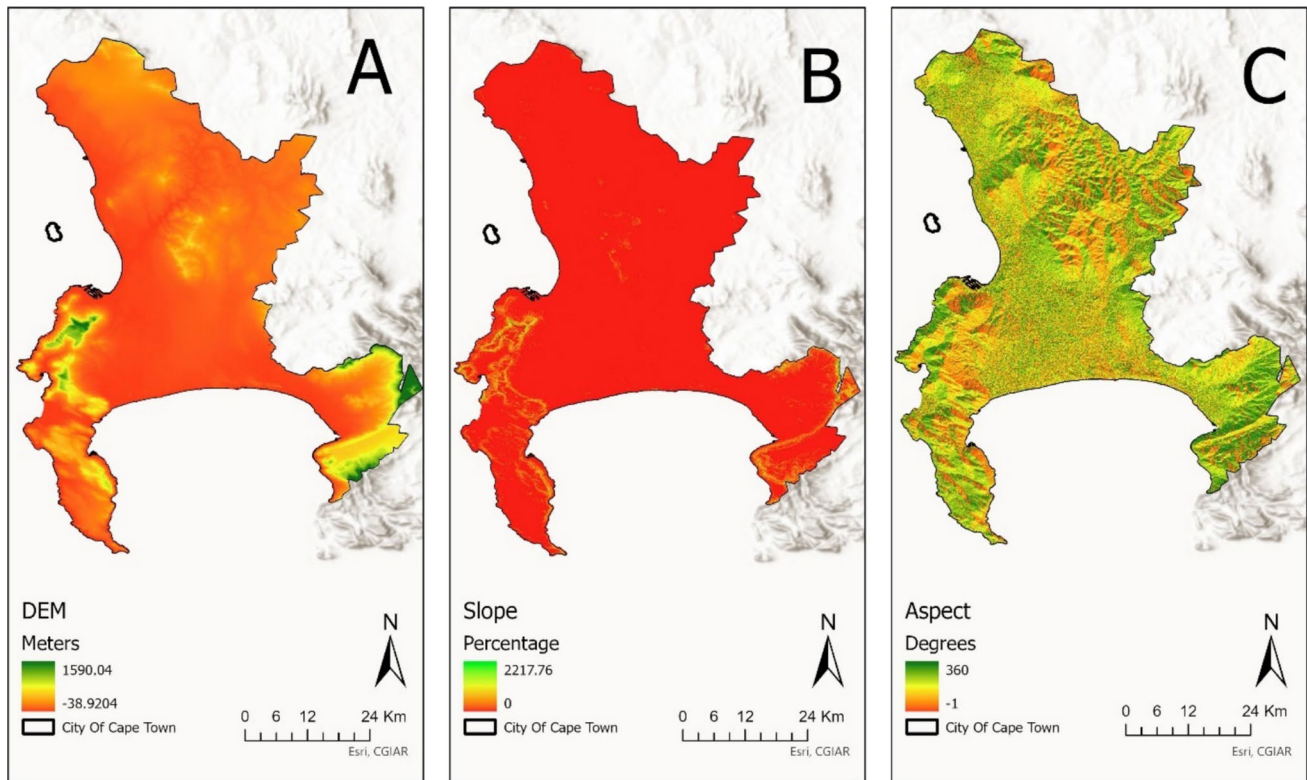
In multicriteria decision analysis via the AHP, the criteria for assessing the suitability of an area are not equally weighted. Each criterion has a weight calculated by assigning scores using the Saaty scale (Saaty 1990). The score for each criterion represents its importance over another criterion when paired. The allocation of the scores was guided on the basis of the rating of the criteria in various literature sources (Cervajal et al. 2022; Castelli et al. 2023; Olivier et al. 2015). The first step in the AHP is to create a pairwise comparison matrix of the criteria. This matrix compares each criterion against another to determine their relative importance in predicting suitable sites for fog harvesting. A value of 1 is assigned because of equal importance when a criterion is compared to itself. The values used are derived from a nine-point scale. Next, a normalised matrix is created by dividing the assigned weight in the original pairwise matrix by the weighted sum of each column. The global weight is generated by summing and dividing the values in each row of the normalised matrix by the number of criteria. When added together, these sums must equal 1. Finally, the criteria are ranked on the basis of their global weight, which represents

the actual weight assigned to them during the weighted overlay process.

To validate the accuracy of the values assigned in the pairwise comparison matrix, a consistency ratio (CR) is computed. The CR determines the likelihood of the observations being true; therefore, it must be less than 0.1 for the matrix to be acceptable. There are several calculations to perform before the CR can be determined. First, a defuzzified matrix is created, and then its sum is determined as the eigenvalue (EV). Next, the number of criteria is subtracted from the EV, multiplied by the number of criteria subtracted from the EV, and multiplied by the number of criteria in less than one to determine the consistency interval (CI). Finally, the CI is divided by a random index (RI) based on the criterion count to compute the CR.

$$CI = (\lambda_n - n) (n - 1) \quad (3)$$

$$CR = CI/RI \quad (4)$$



A: The Digital Elevation Model in meters; B: Slope in percentage derived from the DEM; C: Aspect in degrees derived from the DEM

Fig. 8 Map showing some of the topographic criteria

Weighted overlay

A weighted overlay is commonly used in multicriteria suitability analysis to assess suitability levels on the basis of the input criteria. It follows the general principle of overlay analysis. In this method, the input criterion rasters must be on a standard measurement scale with numerical weights according to their importance (ESRI 2016). The criterion raster layers in this study have already been reclassified into a standard scale of 0–3 after the Euclidean distance calculation, meeting the first condition. The next step in weighted overlay analysis involves multiplying the raster inputs by the corresponding weights calculated using the AHP method. The results of this multiplication are then added together to produce the suitability map. Finally, the result of weighted overlay analysis is multiplied with the Boolean constraint map using a raster calculator to obtain the final suitability map.

Limitations

The secondary data used in this study were obtained from various sources and thus had different resolutions. Harmonising

the diverse datasets into a weighted overlay necessitates resampling each layer to the same spatial resolution. For example, the inverse distance weighting interpolation technique used in this study, although widely employed in spatial data estimation, has certain limitations that can impact its accuracy and applicability. The method relies heavily on the distance between known data points, which can lead to inaccuracies if distant points disproportionately influence the interpolation results (Ruffhead 2023). Additionally, the power exponent employed in inverse distance weighting is often fixed, which may not be optimal for every data point. Allowing for variation in the exponent can improve accuracy, which necessitates additional complexity in the model (Zhang et al. 2024).

Results

Factor and constraint maps

The factor and constraint maps are derived from processes that convert the factors to spatial layers via the methods described in Sect. “[Converting factors to spatial data](#)”. The

Table 3 Criteria thresholds and their corresponding levels of suitability

Scale	Suitability	Range		Wind speed (m/s)	Elevation (m)	Aspect	Slope (%)	Proximity (km)			
		Temperature (°C)	–					Coastline	Residential	Industrial	Transportation
0	Not suitable	–	–	–	200–600	F	<30	>30	>30	<2	>9
1	Less Suitable	15–17	2.2–2.5	2.2–2.5	600–800	NE, SE, E, N	30–60	2.5–30	1.5–30	2–5	6–9
2	Suitable	12–15	2.5–3.5	2.5–3.5	800–1000	S	60–90	1.5–2.5	10–15	5–8	3–6
3	Most suitable	<12	3.5–4.1	3.5–4.1	<200>1000	NW, W, SW	>90	<1.5	<10	>8	<3

DEM, slope and aspect maps representing the topographic criteria are presented in Fig. 8.

The results of the criteria layer harmonisation and reclassification are based on methods described in Sect. “**Criteria layer harmonisation**”. Table 3 presents the varying suitability classes resulting from the reclassification process, while Figs. 9, 10 and 11 display some resulting suitability criterion layers.

As presented in Table 3, areas with elevations below 200 m and above 1000 m, wind speeds between 3.5 and 4.1 m/s, and temperatures less than 12 degrees are classified as the most suitable, scoring 3 out of 3. Similarly, the most suitable aspects for fog harvesting are generally west-facing slopes, including northwest, west, and southwest slopes. Other areas classified as most suitable for fog harvesting are areas along the coast within a proximity of 15 km.

Figure 10A shows that areas depicted in dark green in the southwest and southeast near the mountains have lower temperatures. The high elevations of the mountainous areas combined with the low temperatures characterise these regions as suitable for fog formation and harvesting. In Fig. 10C, the areas within 15 km of the coastline display the highest suitability, depicted in dark green. In contrast, areas farther from the coastline, particularly those beyond 30 km, are not suitable for fog formation and harvesting.

Pairwise matrix and global weights

Assigning the correct weights to criteria layers in a multicriteria suitability study is crucial for weighted overlay analysis. One approach to determining the correct weight is by scoring each criterion based on its importance relative to another criterion using the Saaty scale and creating a pairwise matrix with the scores. The importance of each factor is extracted from the literature, with the factors categorised as topography having greater importance than other categories (Olivier et al. 2015). The elevation factors have the highest importance over the other factors, thus translating to a higher weight than the other factors do. This is followed by the coastline proximity (Carvajal et al. 2022; Castelli et al. 2023; Olivier et al. 2015). Table 4 shows the pairwise comparison matrix based on the importance score of each criterion.

The next step involves creating a normalised matrix. This is done by dividing the weight assigned in the original pairwise matrix by the weighted sum of the column. The global weight is generated when the values in each row of the standardised matrix are summed and divided by the number of criteria, resulting in a total that must equal 1 for each row. Ultimately, this process allows for ranking criteria based on their global weight, as shown in Table 5.

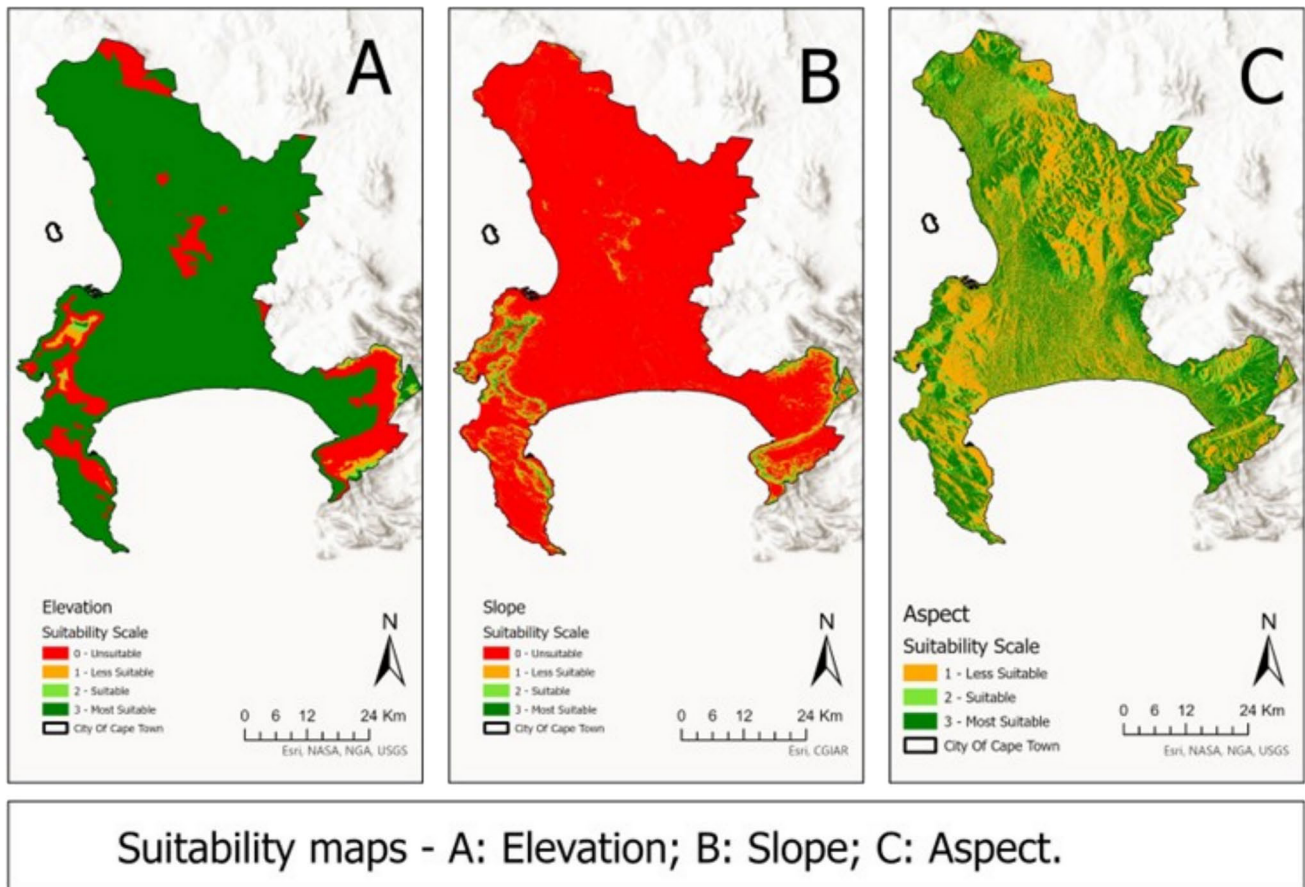


Fig. 9 Map showing the distributions of elevation, slope and aspect for each level of suitability

The elevation criterion has the highest weight and rank, as it is one of the most important criteria for fog formation. This is followed by the coastline criterion, which has a weight of 12.7% and is ranked second. The windspeed criterion is ranked fifth, with a weight of 12.4%, whereas the residential criterion has a weight of 3.3% and is ranked ninth. The pairwise comparison results were further checked for consistency by performing a consistency check. A consistency ratio of 0.0095 was achieved, which is less than 0.10 and confirms the consistency of the pairwise matrix values.

Fog harvesting suitability maps

After the factor layers and weights from the AHP analysis were obtained, they were used as inputs in the weighted overlay analysis to generate suitable areas and their corresponding suitability levels, as shown in Fig. 12. The initial suitability map shows all the suitability levels across the study area before the constraint factors are applied. The areas in dark green represent the most suitable areas, and

the areas in yellow represent the least suitable areas for fog harvesting.

The final suitability map is generated by applying constraints (Fig. 13) to mask out unsuitable areas using a raster calculator. This produces potential sites for fog harvesting within the city of Cape Town, South Africa, as depicted in Fig. 14. The landcover constraint map identifies the green areas in Fig. 13 as suitable for locating fog water harvesting systems, which include grasslands and shrublands. In contrast, industrial, residential, and transportation areas are not suitable.

Areas masked out on the final suitability map in Fig. 14 appear with no colour in the range from green to red. This finding indicates that the siting of fog water harvesting systems is not permitted in those areas, regardless of their potential. Other areas where the siting of fog water harvesting systems is permitted range from green, which is the most suitable, to red, which is the area not suitable for fog harvesting.

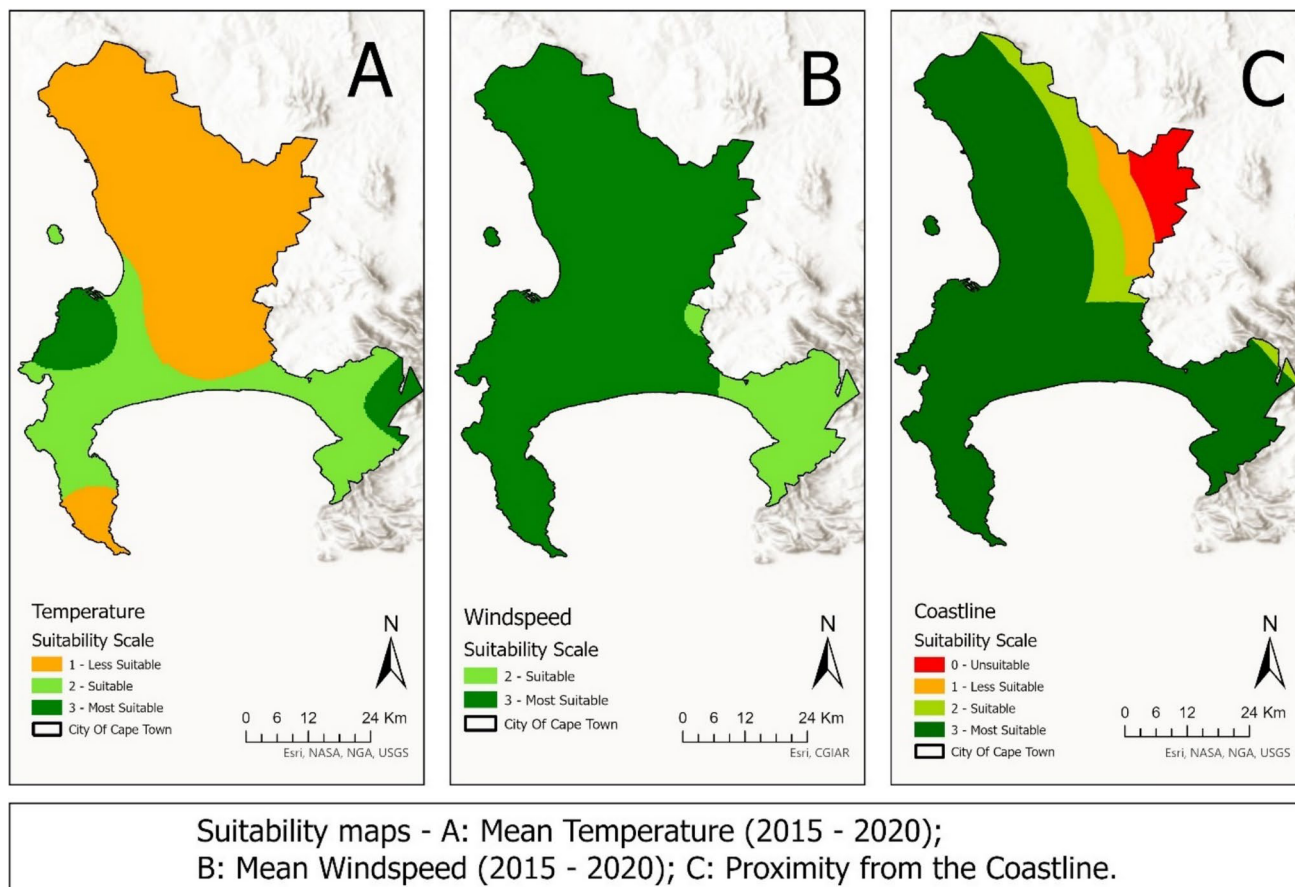


Fig. 10 Map showing the distributions of temperature, wind speed and coastline for each level of suitability

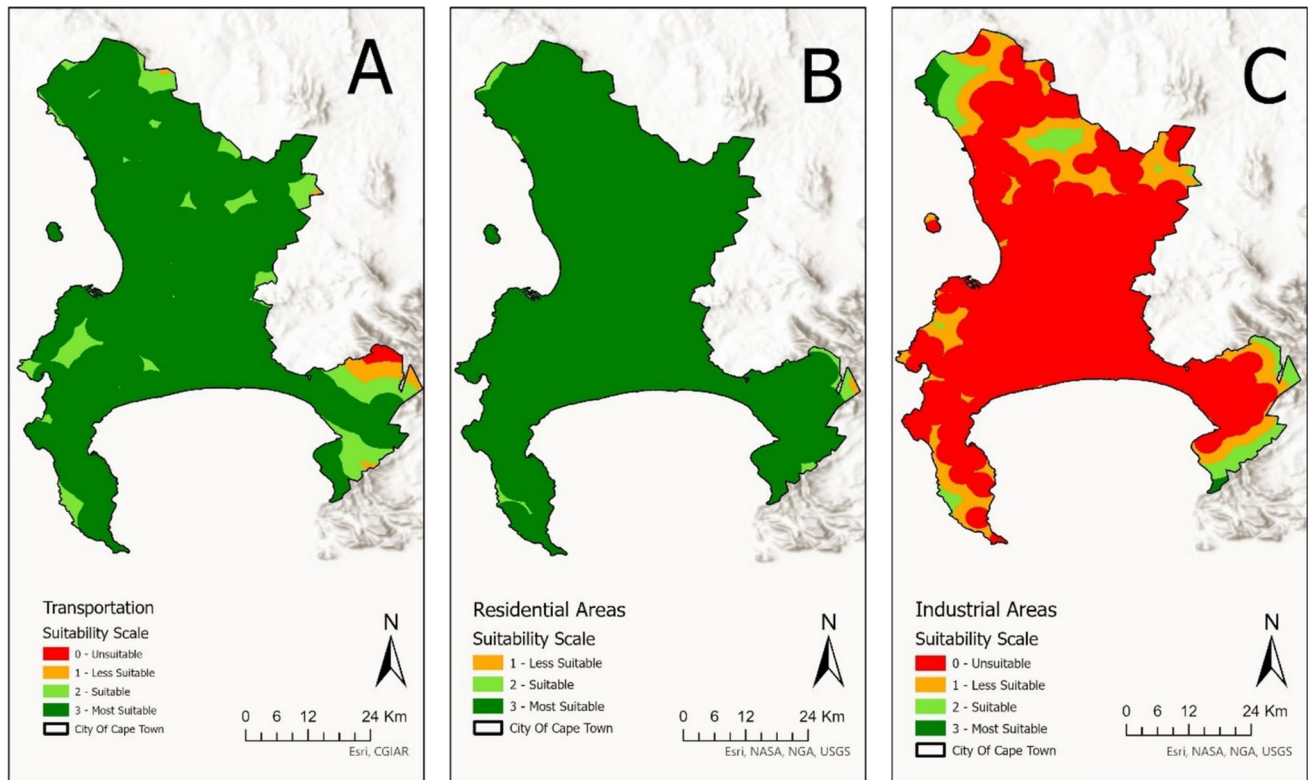
Discussion

Selecting a site for any project is a complex task involving multiple factors to ensure its effectiveness and sustainability. As seen in previous studies, the weights assigned to each factor are determined by their importance over other factors. Elevation is considered one of the most important factors for fog formation. As the temperature decreases and the wind speed increases with increasing elevation, areas with high elevations have the highest potential for fog water harvesting on the west coast (Olivier et al. 2015). Studies and projects conducted across South Africa revealed that areas with elevations greater than 1000 m above sea level have the highest fog water collection potential; however, the exception is along the west coast, where areas with elevations less than 200 m that are within a 15 km proximity from the sea also have high fog water collection rates (Olivier et al. 2015).

Figure 10C shows various proximities of the areas to the coastline, with areas within 15 km being the most suitable.

The proximity to the coastline is another important factor after elevation that affects the intensity and liquid content of fog (Batisha 2015). A study in Bolivia revealed that advective fog (from the ocean) has greater fog collection potential than orographic fog (in the mountains) does (Castelli et al. 2023). Another study in Chile confirmed that fog collection projects within a 12 km proximity yielded almost eight times more fog water than projects situated inland (Cervajal et al. 2022). The next factors in order of importance are aspect and slope. The maritime wind is predominantly a moisture-bearing wind, meaning that ocean-facing steep slopes can intercept it and drive it upslope, where it cools rapidly and forms orographic fog (Olivier et al. 2015). Castelli et al. (2023) also reported that southern Bolivia's best locations for fog harvesting potential lie in areas with slopes facing the Amazon basin.

A comparison of two fog harvesting pilot projects on the west coast of South Africa revealed that more fog water was collected when the wind speed averaged 5.2 m/s at the first



Suitability maps - A: Proximity to Transport networks ; B: Proximity to Residential Areas ; C: Proximity away from Industrial, Waste and mining areas.

Fig. 11 Map showing the range and suitability of areas representing the environmental factors

site than when the average wind speed was 4.3 m/s at the second site (Olivier 2002). Similarly, fog occurs when warm air is cooled and becomes tiny water droplets in the air. Low temperatures have the potential to thicken fog and increase the liquid content in fog (Olivier et al. 2015). Additionally, Carvajal et al. (2022) reported that areas with average temperatures between 10 and 13 degrees had a relatively high fog water collection rate.

Other factors considered in locating suitable sites for fog water collection include proximity to transport systems and residential areas. The process of fog harvesting requires the construction and maintenance of fog water collection systems. The optimal fog harvesting sites must be accessible during construction to enable the delivery of materials, and frequent maintenance is essential for the fog water collection system (Olivier et al. 2015). Similarly, the selected sites must be close to residential areas to minimise the number of distribution channels since most fog harvesting projects aim to provide fresh water to water-stressed, impoverished

communities (Dodson and Bargach 2015). Considering these constraints, it is important to locate fog harvesting sites away from industrial and waste areas that emit pollutants into the air. This ensures that the quality of fog water remains suitable for domestic consumption and agriculture.

Importantly, some of the geographic and climatic factors mentioned above could also be responsible for seasonal variations in fog occurrence, resulting in unique patterns across diverse regions. Empirical evidence suggests that fog is most abundant during particular seasons, with the frequency and form of its occurrence being contingent upon local environmental conditions (Corell et al. 2023).

Since fog harvesting is not commonly practiced, extra care should be taken before investing time and resources in its implementation. Previous studies have often relied on pilot studies to determine the suitability and sustainability of fog harvesting, which could be both time-consuming and expensive. Other potential challenges in scaling up fog harvesting from pilot studies to larger implementations include

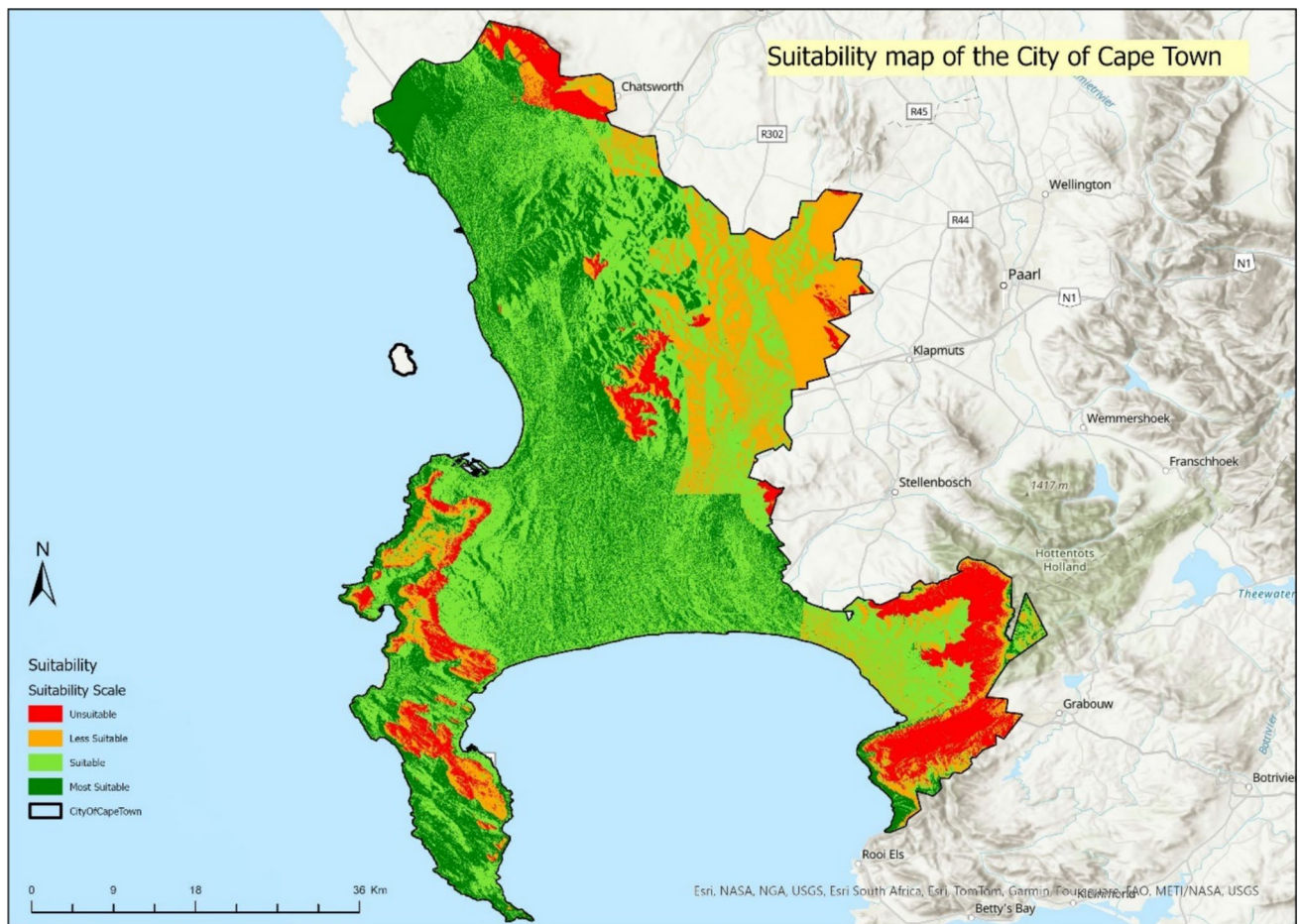


Fig. 12 Map showing the initial suitability map before applying the constraints

technological hurdles such as mesh clogging, efficiency improvements, and social challenges related to community engagement (Mukhopadhyay et al. 2024; Verbrugge and Khan 2023).

The methods and data used to identify potential fog water collection locations in this study are efficient, cost effective, and eliminate the need for field visits, unlike the approach taken by Karimidastenaeci et al. (2020), which requires collecting samples at various locations within the study area. Figure 14 reveals that the concentration of the areas most suitable for fog harvesting in Cape Town is found in the northwestern, southeastern, western, and southwestern regions, primarily because of the high-elevation peaks and ocean-facing steep slopes. Low temperatures and proximity to industrial areas. In the northwestern part, there are steep ocean-facing slopes, proximity to the coast, elevations lower than 200 m, higher wind speeds, and proximity away from industrial areas.

Table Mountain, situated in the western part of the study area, falls within the most suitable areas identified in the

suitability analysis carried out and is shown on the final suitability map in Fig. 14. This area is characterised by proximity to the ocean, steep ocean-facing slopes, high wind speeds, and high-elevation mountain ranges. The city of Cape Town (CoCT) launched a fog harvesting pilot project on Table Mountain in 2020, further validating the suitability analysis and results from this study (CoCT 2020). Additionally, our findings align with studies conducted in similar geographical areas where South Africa's west coast sites were evaluated for fog harvesting potential (Olivier 2002, 2004). Similarly, Chile, a semiarid region similar to South Africa, has successfully harvested fog (Carvajal et al. 2022; Di Bitonto et al. 2020). A particular fog called "camanchaca" forms over the ocean and is carried to the Chilean coast by winds. Camanchaca fog occurs at altitudes of approximately 1000 m above mean sea level and is present along the northern Chilean coastline. A study conducted between 1998 and 2000 reported the potential to harvest

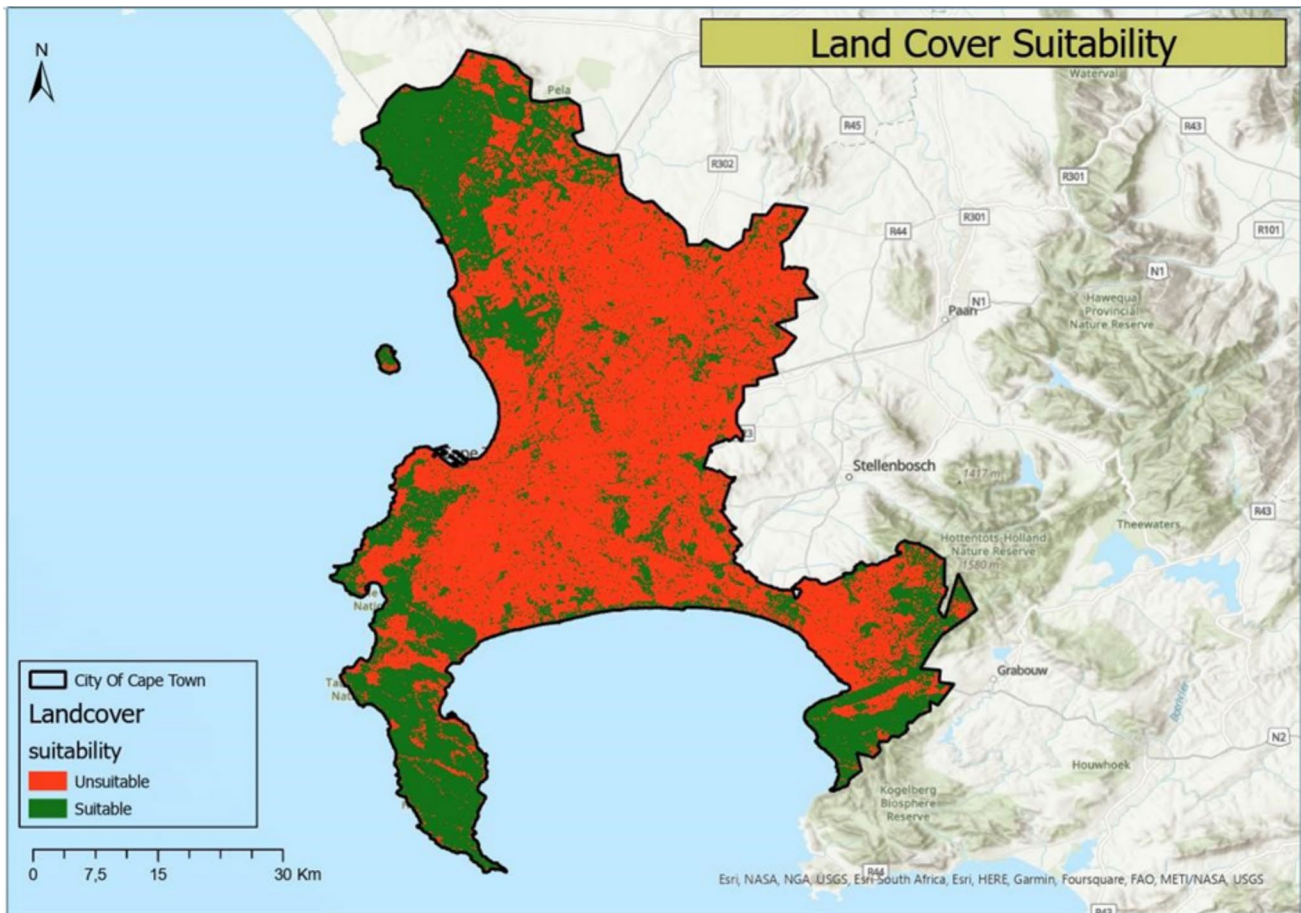


Fig. 13 Map showing areas that are suitable and unsuitable on the basis of the constraints

1.43 L of water per day per square metre of Rachel mesh with 35% shading (Di Bitonto et al. 2020).

Findings from these studies imply that fog forms mostly along the coast at high altitudes, thus confirming some factors and criteria weights considered in our study. Possible limitations of this study's analysis and findings may include challenges in accessing potentially suitable sites, especially high-elevation areas, as the investigation is entirely remote sensing-based without any field visits. Therefore, the results of this study can aid decision-making processes in selecting suitable locations for fog water collection across regions with comparable climatic conditions.

Conclusions

This study aims to streamline the process of identifying suitable locations for fog water collection by using GIS-based multicriteria decision analysis. To achieve this goal, relevant

factors influencing fog formation and harvesting were identified from the literature and converted to spatial data layers. The factor and criteria layers were subsequently harmonised to a similar spatial extent, resolution, and scale before assigning weights to each factor using the AHP technique. Finally, the factor layers were combined in a weighted overlay to determine suitable locations for fog water collection in the city of Cape Town. The results of this study revealed that areas in the western and southern regions are most suitable for fog water collection. Therefore, serving as a potential decision-making tool for planning to achieve water security in arid and semiarid regions, as aligned with goal 6 of the United Nations Sustainable Development Goals: ensuring universal access to clean water and sanitation. Future research could investigate the efficacy of the methods used in this study across diverse geographical and climatic settings.

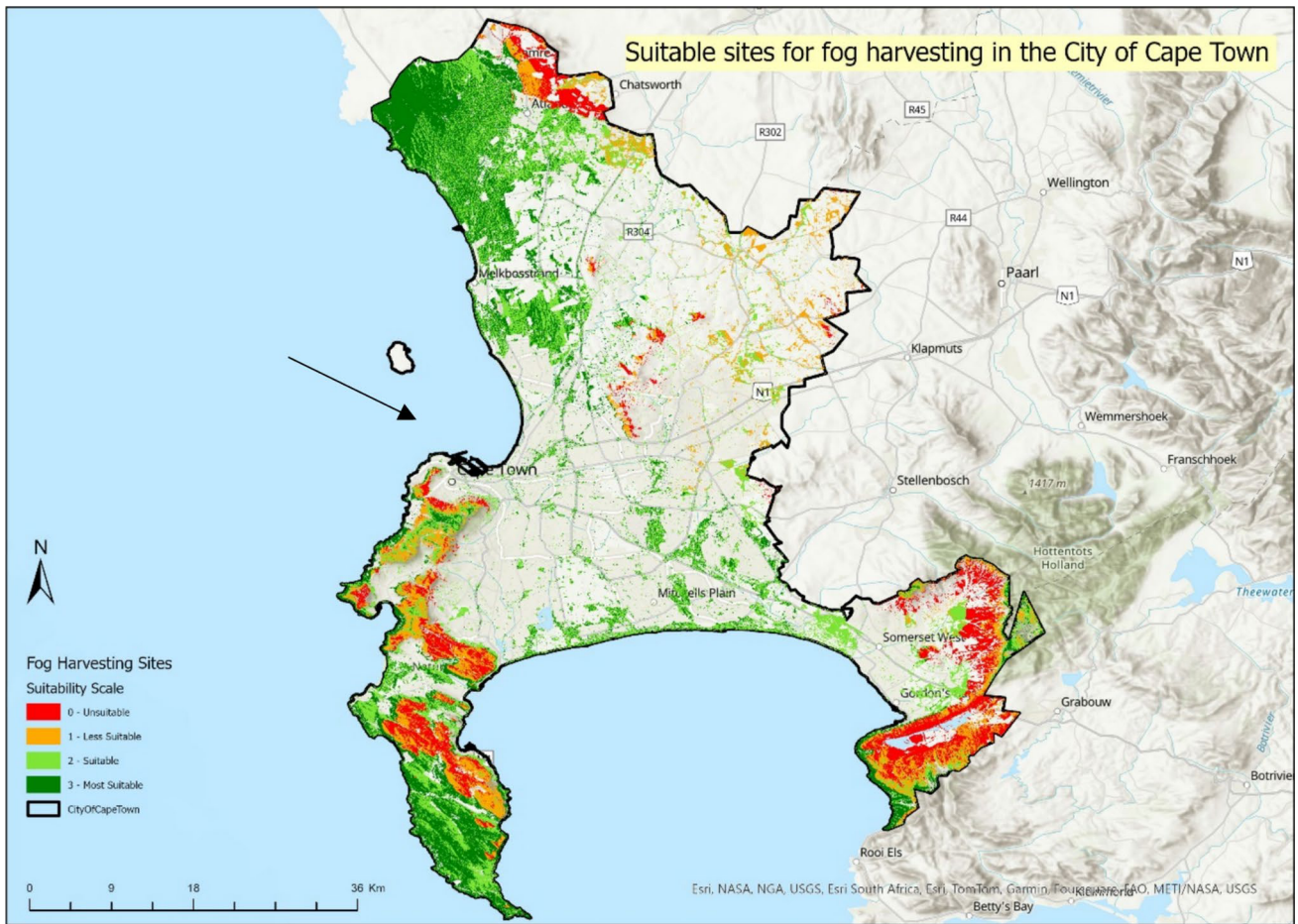


Fig. 14 The final suitability map shows areas with varying suitability levels for fog harvesting

Table 4 Pairwise matrix showing how each criterion compares to others

Pairwise comparison									
Factors	Transport	Residential	Industrial	Temperature	Wind speed	Elevation	Aspect	Slope	Coastline
Transport	1.00	3.00	1.00	0.50	0.50	0.33	0.50	0.50	0.33
Residential	0.33	1.00	0.33	0.33	0.25	0.25	0.25	0.25	0.25
Industrial	1.00	3.00	1.00	0.50	0.50	0.50	0.50	0.50	0.50
Temperature	2.00	3.00	2.00	1.00	1.00	0.50	1.00	1.00	1.00
Wind speed	2.00	4.00	2.00	1.00	1.00	0.50	1.00	1.00	1.00
Elevation	3.00	4.00	2.00	2.00	2.00	1.00	2.00	2.00	2.00
Aspect	2.00	4.00	2.00	1.00	1.00	0.50	1.00	1.00	1.00
Slope	2.00	4.00	2.00	1.00	1.00	0.50	1.00	1.00	1.00
Coastline	3.00	3.00	2.00	1.00	1.00	0.50	1.00	1.00	1.00

Table 5 The normalised matrix, global weight, and criteria ranking

	Transport	Residential	Industrial	Temperature	Wind speed	Elevation	Aspect	Slope	Coastline	GW	Weights (%)	Ranking
Transport	0.061	0.103	0.070	0.060	0.061	0.072	0.061	0.061	0.041	0.065	6.546	8
Residential	0.020	0.034	0.023	0.040	0.030	0.055	0.030	0.030	0.031	0.033	3.268	9
Industrial	0.061	0.103	0.070	0.060	0.061	0.109	0.061	0.061	0.062	0.072	7.193	7
Temperature	0.122	0.103	0.140	0.120	0.121	0.109	0.121	0.121	0.124	0.120	12.023	6
Windspeed	0.122	0.138	0.140	0.120	0.121	0.109	0.121	0.121	0.124	0.124	12.406	5
Elevation	0.184	0.138	0.140	0.240	0.242	0.218	0.242	0.242	0.248	0.210	21.048	1
Aspect	0.122	0.138	0.140	0.120	0.121	0.109	0.121	0.121	0.124	0.124	12.406	3
Slope	0.122	0.138	0.140	0.120	0.121	0.109	0.121	0.121	0.124	0.124	12.406	4
Coastline	0.184	0.103	0.140	0.120	0.121	0.109	0.121	0.121	0.124	0.127	12.703	2
Sum (column)	1	1	1	1	1	1	1	1	1	1	100	

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Data availability Datasets generated during the current study are available from the corresponding author upon reasonable request.

Declarations

Conflict of interest On behalf of all the authors, the corresponding author states that there are no conflicts of interest.

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References

Batisha AF (2015) Feasibility and sustainability of fog harvesting. *Sustain Water Qual Ecol* 6:1–10

Carvajal D, Mora-Carreño M, Sandoval C, Espinoza S (2022) Assessing fog water collection in the coastal mountain range of Antofagasta, Chile. *J Arid Environ* 198:104679

Castelli G, Sanchez AC, Mestrallet A, Montañó LC, de Armentia TL, Salbitano F, Bresci E (2023) Fog as unconventional water resource: mapping fog occurrence and fog collection potential for food security in southern Bolivia. *J Arid Environ* 208:104884

Cereceda P, Osses P, Larrain H, Farias M, Lagos M, Pinto R, Schemenauer R (2002) Advective, orographic and radiation fog in the Tarapacá region, Chile. *Atmos Res* 64(1–4):261–271

CoCT (2020) What the fog is happening on table mountain? Cape Town: City of Cape Town, Media Office.

Cole HD, Cole MJ, Simpson KJ, Simpson NP, Ziervogel G, New MG (2021) Managing city-scale slow-onset disasters: learning from cape town’s 2015–2018 drought disaster planning. *Int J Disaster Risk Reduct* 63:102459

Corell D, Estrela MJ, Valiente JA (2023) Seasonal behaviour and influence of altitude on fog-water collection in the eastern Iberian Peninsula (2003–2012). *Int J Climatol* 43(4):1935–1954

CTCN (2017) Fog harvesting Copenhagen, Denmark; Accessed 14 Feb 2024]. <https://www.ctc-n.org/products/fog-harvesting>

Di Bitonto MG, Angelotti A, Zanelli A (2020) Fog and dew harvesting: Italy and Chile in comparison. *Int J Innov Res Dev* 9(3):132–140

Dodson LL, Bargach J (2015) Harvesting fresh water from fog in rural morocco: research and impact dar si hmad’s fogwater project in aït baamrane. *Proc Eng* 107:186–193

ESRI (2016) How weighted overlay works environmental systems research institute, Inc.; [Accessed 07Feb 2022]. <https://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/how-weighted-overlay-works.htm>

ESRI (2024) How inverse distance weighted interpolation works; [Accessed 16 Feb 2024]. <https://pro.arcgis.com/en/pro-app/3.1/>

- help/analysis/geostatistical-analyst/how-inverse-distance-weighted-interpolation-works.htm
- Fessehaye M, Abdul-Wahab SA, Savage MJ, Kohler T, Gherezghier T, Humi H (2014) Fog-water collection for community use. *Renew Sustain Energy Rev* 29:52–62
- Gandhidasan P, Abualhamayel HI, Patel F (2018) Simplified modeling and analysis of the fog water harvesting system in the Asir region of the kingdom of Saudi Arabia. *Aerosol Air Qual Res* 18(1):200–213
- Hartmann K, Krois J, Rudolph A (2023) Statistics and geodata analysis using r (soga-r); department of earth sciences, freie universitaet berlin.
- Hünová I, Brabec M, Malý M, Dumitrescu A, Geletič J (2021) Terrain and its effects on fog occurrence. *Sci Total Environ* 768:144359
- Karimidastanaei Z, Haghighi AT, Rahmati O, Rasouli K, Rozbeh S, Pirmia A, Pradhan B, Kløve B (2020) Fog-water harvesting capability index (fci) mapping for a semi-humid catchment based on socio-environmental variables and using artificial intelligence algorithms. *Sci Total Environ* 708:135115
- Klemm O, Schemenauer RS, Lummerich A, Cereceda P, Marzol V, Corell D, Van Heerden J, Reinhard D, Gherezghier T, Olivier J (2012) Fog as a fresh-water resource: overview and perspectives. *Ambio* 41:221–234
- Louw C, Van Heerden J, Olivier J (1998) The south african fog-water collection experiment: meteorological features associated with water collection along the eastern escarpment of south africa. *WATER SA-PRETORIA-* 24:269–280
- Maria E, Budiman E, Taruk M (2020) Measure distance locating nearest public facilities using haversine and euclidean methods. *J Phys Conf Ser* 2020: IOP Publishing
- Mukhopadhyay A, Datta A, Dutta PS, Datta A, Ganguly R (2024) Droplet morphology-based wettability tuning and design of fog harvesting mesh to minimize mesh-clogging. *Langmuir* 40(15):8094–8107
- Olivier J (2002) Fog-water harvesting along the west coast of South Africa: a feasibility study. *Water Sa* 28(4):349–360
- Olivier J (2004) Fog harvesting: an alternative source of water supply on the west coast of South Africa. *GeoJournal* 61:203–214
- Olivier J, De Rautenbach C (2002) The implementation of fog water collection systems in South Africa. *Atmos Res* 64(1–4):227–238
- Olivier J, Van Heerden J (2003) Implementation of an operational prototype fog water collection system: Project implementation. Report to the water research commission WRC report. (902/1) 02
- Olivier J, Van Heerden J, Rautenbach H, Association IRCS (2015) Optimising fog water harvesting in south africa. Water Research Commission.
- Qadir M, Jiménez GC, Farnum RL, Trautwein P (2021) Research history and functional systems of fog water harvesting. *Front Water* 3:675269
- Qu X, Brame J, Li Q, Alvarez PJ (2013) Nanotechnology for a safe and sustainable water supply: enabling integrated water treatment and reuse. *Acc Chem Res* 46(3):834–843
- Ruffhead AC (2023) Enhancement of inverse-distance-weighting 2D interpolation using accelerated decline. *Rep Geodesy Geoinform* 116(1):9–14
- Saaty TL (1990) How to make a decision: the analytic hierarchy process. *Eur J Oper Res* 48(1):9–26
- Treasury WCP (2012) Regional development profile: City of cape town. City of Cape Town: Western Cape Government 8–12.
- United Nations (2015) Ensure availability and sustainable management of water and sanitation for all; [Accessed 13 Feb 2024]. <https://sdgs.un.org/goals/goal6>
- Verbrugge N, Khan AZ (2023) Water harvesting through fog collectors: a review of conceptual, experimental and operational aspects. *Int J Low-Carbon Technol* 18:392–403
- Zhang B, Cao J, Lin S, Song Y (2025) Reconstruction of γ dose rate field and algorithm validation based on inverse distance weight interpolation. *Nucl Technol* 211(1):1–2

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