SITE SUITABILITY ANALYSIS FOR A GREENFIELD AIRPORT IN KOLKATA USING GIS AND REMOTE SENSING

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ABSTRACT

Geographic Information Systems (GIS) and Remote Sensing are widely recognized as a valuable tool for capturing, storing, manipulating, analysing, managing and displaying all types of geographical data. Due to the complex nature of airport planning modalities, the potential of GIS applications in resolving several issues on airports is increasingly acknowledged by many. In this paper, we have discussed some of the potential benefits of ArcGIS applications in airport site selection. Using site suitability analysis an attempt has been made by the authors to find the most suitable and feasible sites for the construction of a greenfield airport in Kolkata, West Bengal, India. Here, the study takes into consideration the most import and likely factors such as slope, drive-time buffer, land use/land cover information, restricted zones and the prevailing meteorological conditions. Accordingly, different candidate sites for the new airport have been analyzed. The study also highlights the role of such a multi-criteria approach performed within the step by step decision-making process concerning the site selection for recommending five different sites for the plausible development of a new airport at Kolkata.

1. INTRODUCTION

Across the globe, several countries are increasing their budget to spend on new technology in the field of aviation. As the passenger traffic has been increasing at an alarming rate which is expected to reach 370 million by 2020, this would undoubtedly make India as the world's 3rd largest aviation market. The total passenger traffic of India (both domestic as well as international) has increased by almost four times from 73.35 million in the financial year (April to March) 2006 to 280.24 million in 2018. The busiest airports of India have been Indira Gandhi International Airport (Delhi) followed by Chhatrapati Shivaji International Airport (Mumbai), Kempegowda International Airport (Bengaluru), Chennai International Airport (Chennai) and Netaji Subhas Chandra Bose International Airport (Kolkata) respectively. Kolkata airport is located in the Dum Dum region which is about 17 km from the central city area and around 5 km from the industrial IT hub area. It is one of the largest in eastern India and since it is the only international airport of the state, it has become an aviation hub that handles more than 9 million passengers per year. Due to the growth of airlines such as SpiceJet, Indigo, GoAir, and Jet, the number of passengers at the airport gradually rose resulting in overcrowding of the two terminals of the airport. To curb this, an exhaustive modernization plan was developed for the airport which included expansion of parking bays, rapid-exit taxiways, main runways, existing terminals, cafes, ticketing counters, check-in kiosks, etc. which led to a plan for a full-fledged new integrated terminal for both international as well as domestic passengers. The new environment-friendly terminal increased the overall capacity of the airport to over 20 million passengers per year. Land at the Kolkata airport is highly constrained to create such a separation as the boundary wall is located to the east and the terminal building to the west. Due to these limitations, the second runway at the airport is only used in exceptional cases when the primary runway is shut down due to emergency or maintenance purposes. Exacerbating this problem is the issue of a limited number of parking bays in the airport. Although more bays have been planned, it will only be a matter of a few years before they too will get saturated. Moreover, acquiring more land in the vicinity of the airport is an impossible task due to the dense population around.

As a solution to the above problems, the Kolkata Government suggested the Kazi Nazrul Islam Airport at Andal near Durgapur. The distance between both airports is nearly 190 km which means that if you fly from one airport to the other it would take around 20-25 minutes. According to aviation experts, a city airport should be ideally located within a two-hour drive from the city but the travel time from NSCB airport to Kazi Nazrul Islam airport is over 3 hours. Thus, due to this large separation between the two, the second airport has to be closer to the city and Durgapur cannot serve this purpose. Another alternative suggested by the government was the Behala Airport located in the city of Kolkata. It is the second of the two airports that exist in the Kolkata Metropolitan Area and both the Airports Authority of India (AAI) and the Ministry of Civil Aviation, India has plans to develop it into a fully functioning commercial airport in the coming years by initially expanding the existing runway to 1380 meters. Even if this is done, taking into consideration the limited land available for expansion of the airport, most modern day commercial aircraft, for example the Airbus A320 ideally requires between 3000-7000 feet of runway for landing and taking off. That means even if the runway is extended to 4500 feet it would be insufficient for most aircraft to carry out safe operations in this area. Therefore, this also rules out the possibility of Behala Airport being used as a second airport for Kolkata. All these problems justify the need for a new Greenfield Airport for Kolkata.

2. METHODOLOGY

The selection of a suitable site for an airport is usually a complex task and it depends on several factors such as: regional plan, airport use, proximity to other airports, ground accessibility, topography, obstructions, visibility, wind conditions, noise nuisance, grading, soil as well as drainage characteristics, future development opportunities and economic considerations. In this study, the site suitability analysis is carried out based on the following parameters: slope, drive-time buffer, land use/land cover information, restricted zones and meteorological conditions as explained below.

(i) Drive-time buffer: According to most airport officials, an airport ideally needs to be located within a drive-time of around one and a half hours or at most two hours away from the centre of the city. Here, we used the 'Create Drive-Time Areas tool' in ArcGIS Online to create a two-hour drive time-buffer around the city of Kolkata using the Esri service areas to calculate the areas that can be reached in a travel time or distance specified by a street network based on travel mode. This tool configures the transit of vehicles such as cars and finds alternatives to optimize travel time. The driving speed taken into consideration was based on historical data and live traffic information that depicts actual conditions in reality. This layer was then exported to ArcMap and it was saved in shapefile format.

(ii) Slope: The runway of the airport ideally needs to be as flat as possible so that excessive engine thrust can be avoided. This is because, if there are a number of longitudinal gradients then a kink is formed at their intersection and; as the aircraft crosses this kink there exist chances of a structural disability causing deformation within the body of the aircraft. The International Civil Aviation Organization (ICAO) specified that the maximum limit of slope for airports that serve large aircraft should be between 1.25% and 1.5%. In this regard, elevation data was downloaded from the 30m SRTMTile downloader website created by Derek Watkins. The Shuttle Radar Topography Mission (SRTM), 1 Arc-Second Global provides open distribution of worldwide coverage of void filled data at a high resolution of 1 Arc-Second or 30ms. This product uses 'Geographic Projection', WGS84 as the horizontal datum and its vertical units are in meters. A NASA Earth data login (can be freely created) was required to access this data which provides a single mechanism for user registration and profile management for all Earth Observing System Data and Information Systems (EOSDOS) components. Hence, the following tiles were downloaded: N21E087, N21E088, N21E089, N22E087, N22E088, N22E089, N23E087, N23E088 and N23E089 and a mosaic dataset was created respectively in ArcMap 10.4.1 using the 'Mosaic to New Raster Tool'. The downloaded tiles had a single band and the same bit depth, so they were directly taken as input in the tool. Coordinate system was specified as 'WGS84' and the output mosaic raster was exported as a 'TIFF' file. It was also masked to the two-hour drive time buffer shapefile using the 'Extract by Mask tool' (Spatial Analyst) of ArcMap. Then the 'Define Projection Tool' was used to convert the raster from Geographic Coordinate System (GCS) to Projected Coordinate System (PCS), i.e. 'WGS_1984_UTM_Zone_45 N' in which the units are measured in meters. The slope was then calculated in degrees using the 'Slope tool' which can be found in the 'Surface toolset' which is part of the 'Spatial Analyst toolbox' in ArcMap. This tool calculates the maximum rate of change in value for each cell compared to its neighbours, i.e. the maximum change in elevation over the distance between the cell and its eight neighbours identifies the steepest downhill descent from that cell. Suitable symbology was assigned to the slope that was generated by this tool. The next step is the 'Reclassify tool' which is part of the 'Spatial Analyst Extension' was used to assign a value of '1' to areas with suitable slope for the construction of the airport (i.e. with values of slope less than 1.25 degrees) and '0' to the rest of the areas which were unsuitable for construction. The 'Reclassified Slope' would be used as the first input to the 'Weighted Overlay tool'.

(iii) Land Use/Land Cover: Land use information is crucial while selecting a site for a new airport. The existing land use pattern has to be analyzed and suitable land cover types must be chosen where airport construction is feasible. We downloaded the LULC map (1:250000 scale) of West Bengalfrom Bhuvan's website which is managed by the National Remote Sensing Centre (NRSC). The LULC 250k database has been prepared using the satellite data from the Resourcesat-II Awifs data product. Thirteen cycles have been completed starting from 2004-2005 to 2016-2017 and the content accuracy of this classification is between 82-92%. The downloaded TIFF file was masked to the two-hour drive time buffer shapefile and appropriate symbology was assigned to various classes present in the raster. On the basis of suitability, the 'Reclassify tool' was used to assign proper weightage to the different classes. Most of the land in the outskirts of the city consists of crops and plantation. There are large areas where kharif (7.55% of the total area), zaid (0.13%) and rabi (5.89%) cultivation is being done and other areas where fallow land is present (4.01%). Such areas may be acquired by the government and the airport can be constructed on such land. That is why they have been given a weightage of 9 (i.e. extremely suitable). Other forms of cultivation include double and triple crops and plantations constituting 24.2% and 20.7% of the total area respectively. Both these classes have been given lesser weightage value of 7 compared to the previous classes since extensive cultivation is carried out here and these crops yield more than once or twice per year. Deciduous and Degraded/Scrub forests account for 8.09% and 0.24% respectively of the total study area taken into consideration. They have been given an even lesser weightage value of 5 since it is very difficult to construct airports in such areas. This would require clearing large sections of the forest which will severely affect the local environemnt and other works such as rock cutting and blasting have to be done prior to the levelling of land for construction purpose. Littoral swamps, grassland and wasteland combined together only accounts for 0.10% of the study area. Thus, they have been given the least weightage value of 3 (moderately suitable) in the ranking process. Such areas have issues like water loggging which make them unfit for airport construction unless they are completely reconstructed to suit the purpose. Built-up area and water bodies cannot be used for construction purpose, so they were assigned a weightage of zero (not suitable). The final output, i.e. the 'Reclassified LULC' would be used as the second input to the 'Weighted Overlay tool'.

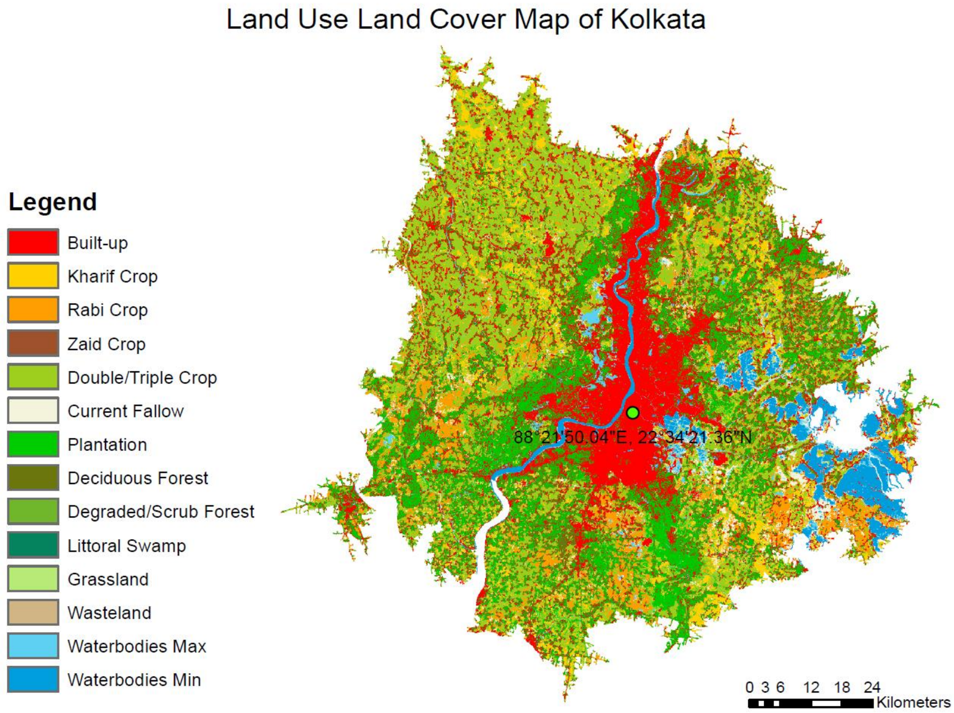

Figure 1. Land Use Land Cover map of Kolkata (Two-hour drive time buffer from the city centre)

(iv) Restricted Areas: Many areas in the state of West Bengal are restricted zones/protected areas such as biosphere reserves and national parks. National parks and sanctuaries are areas of significant ecological, floral, faunal or of natural significance. They are notified by the State Governments and protected by the Forest Departments under the provisions of the Wildlife (Protection) Act, 1972 & its amendments, Indian Forest Act of 1927, Forest (Protection) Act of 1980, Biological Diversity Act, 2002 and the Scheduled Tribes and Other Traditional Forest Dwellers (Recognition of Forest Rights) Act, 2006. Hunting of wild animals, encroachment and/or destruction of habitat, construction of tourist lodges and other such activities are prohibited in protected areas. These areas were digitized using Google Earth Pro and exported in kml/kmz format. These files were converted to layer format in ArcMap using the 'KML to Layer tool' which is part of the 'Conversion Tools' in ArcToolbox and finally merged into a single shapefile using the 'Merge Tool' which is part of the 'Data Management tools' in ArcMap. Built-up area and other large water bodies have already been excluded using the 'Reclassify tool' earlier. Construction cannot be done in the path of rivers or perennial streams. So a buffer of one kilometre was generated using the 'Buffer tool' (Analysis) on either side of rivers and it was classified as restricted since construction is not feasible here. The final restricted area map was saved in layer format. These areas were removed from our study area using the 'Extract by Mask tool' which is part of the 'Spatial Analyst toolbox' in ArcMap. Now that the input files have been generated, the 'Weighted Overlay tool' was used to generate the site suitability map for Kolkata. The importance given to the slope was 60% and land use/cover was given 40% weightage.

Weighted Overlay tool allows the calculation of a multiple-criteria analysis between several rasters. It was achieved through the following steps: reclassifies values in the rasters taken as input and combines them into an evaluation scale of suitability or preference risk, multiplies the cell values of each input by the rasters weight of importance and adds the resulting cell values together to produce the final suitability raster where value '0' represents not suitable and value '4' corresponds to most suitable. Based on the visual interpretation of the suitability raster, six different candidate sites (Fig.2) having dimensions of about 6x4 km were identified for the construction of the new airport, in order to accommodate at least 4 runways making it futureproof and also keeping in mind the scope for future expansion of the airport.

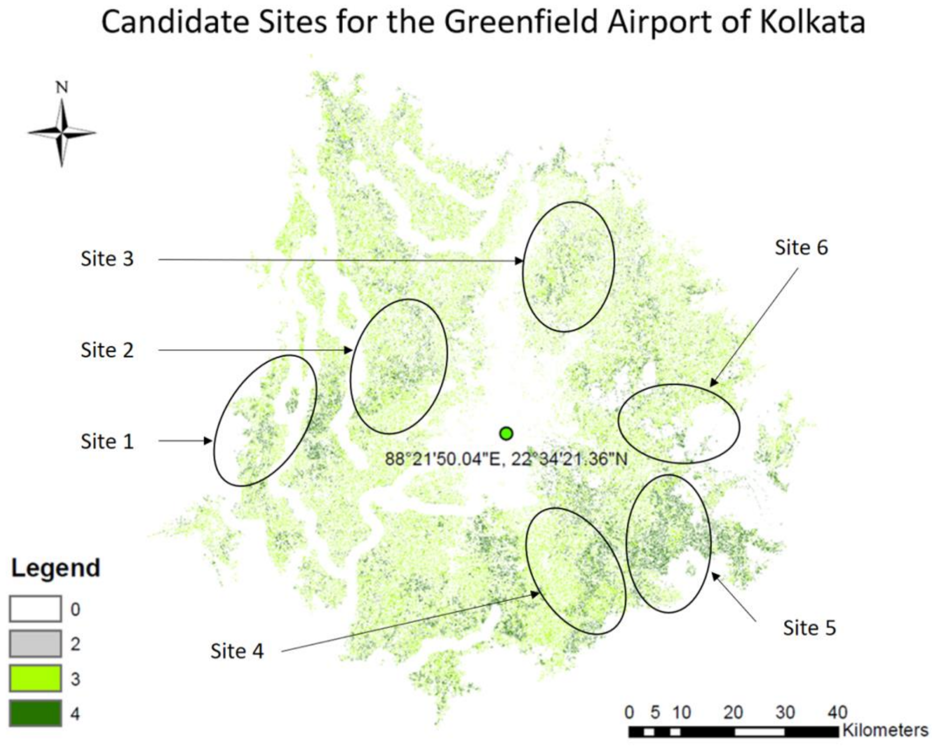

Figure 2. Candidate Sites for Kolkata's Greenfield Airport

(v) Meteorological Conditions: Factors like wind, visibility, temperature and humidity play a major role in airport site selection. It is most important to understand the direction, intensity and duration of winds in a specific site/region considered. If the wind intensity is too high, a resistance or uplift condition might be created to standby aircraft and this can pose to be a safety hazard condition, restricting movement or operation of aircraft. When the wind blows in the opposite direction to the landing of aircraft it produces a braking effect which is favourable for landing. Similarly, when the aircraft takes off in the direction of the wind it provides greater lift. Because of this, runways are generally constructed in the direction of the wind after analyzing the historical wind data of that particular location. We downloaded wind data for the past ten years (from 01-01-2008 00:00 hours to 31-05-2018 23:00 hours) from the Modern-Era Retrospective Analysis for Research and Applications, Version 2 (MERRA-2). This database was introduced to replace the original MERRA dataset because of technological advances made in the assimilation system that enabled assimilation of modern hyperspectral radiance and microwave observations, along with GPS-Radio Occulation datasets. The meteorological dataset had a temporal resolution of one hour and it was regridded using bilinear interpolation into the 'geos 0.25' gid format. The downloaded NetCDF files consisted of four variables: **u** component of wind at 10m height (Northward direction), **v** component of wind at 10m height (Eastward direction), air temperature at 10m height and the specific humidity at 10m height respectively. We used R programming language to read and extract data from these files. The output was saved to an excel sheet and the wind rose diagram was plotted using WRPLOT View which is a free software that provides visual wind rose plots, frequency analysis and plots for several meteorological data formats.

A wind rose as indicated above depicts the frequency of occurrence of winds in each of the specified wind direction sectors and wind speed classes for a given location and time period. From this wind coverage can be understood, which is nothing but the usability factor of the airport expressed as a percentage of time in a year during which cross wind component remains within the limit or when runway operations are not restricted due to excessive cross wind component. ICAO and FAA recommendations state that the minimum wind coverage at a given airport should be at least 95% which is accepted globally. It means that a single runway or a set of parallel runways can be oriented as such to provide the required wind coverage as per specifications. If a single runway is not able to provide the required coverage then an additional runway may be constructed in another direction such that the combined wind coverage of both runways should be more than 95%. As per official regulations, the calm period is when the wind intensity is below 6.4 km/hr and this by default is considered common to all directions and thus can be added to the overall wind coverage, to sum up to at least 95%. The wind data was imported from the excel sheet and the meteorological station was added. This way, the wind rose diagram was generated to understand wind direction and intensity and from the wind frequency districution table using the appropriate algorithm to find out the best possible orientation of the runway on the basis of historical wind data. The algorithm used requires to plot the wind duration diagram and their respective values for different classes of wind speeds in various sectors or directions from the origin.

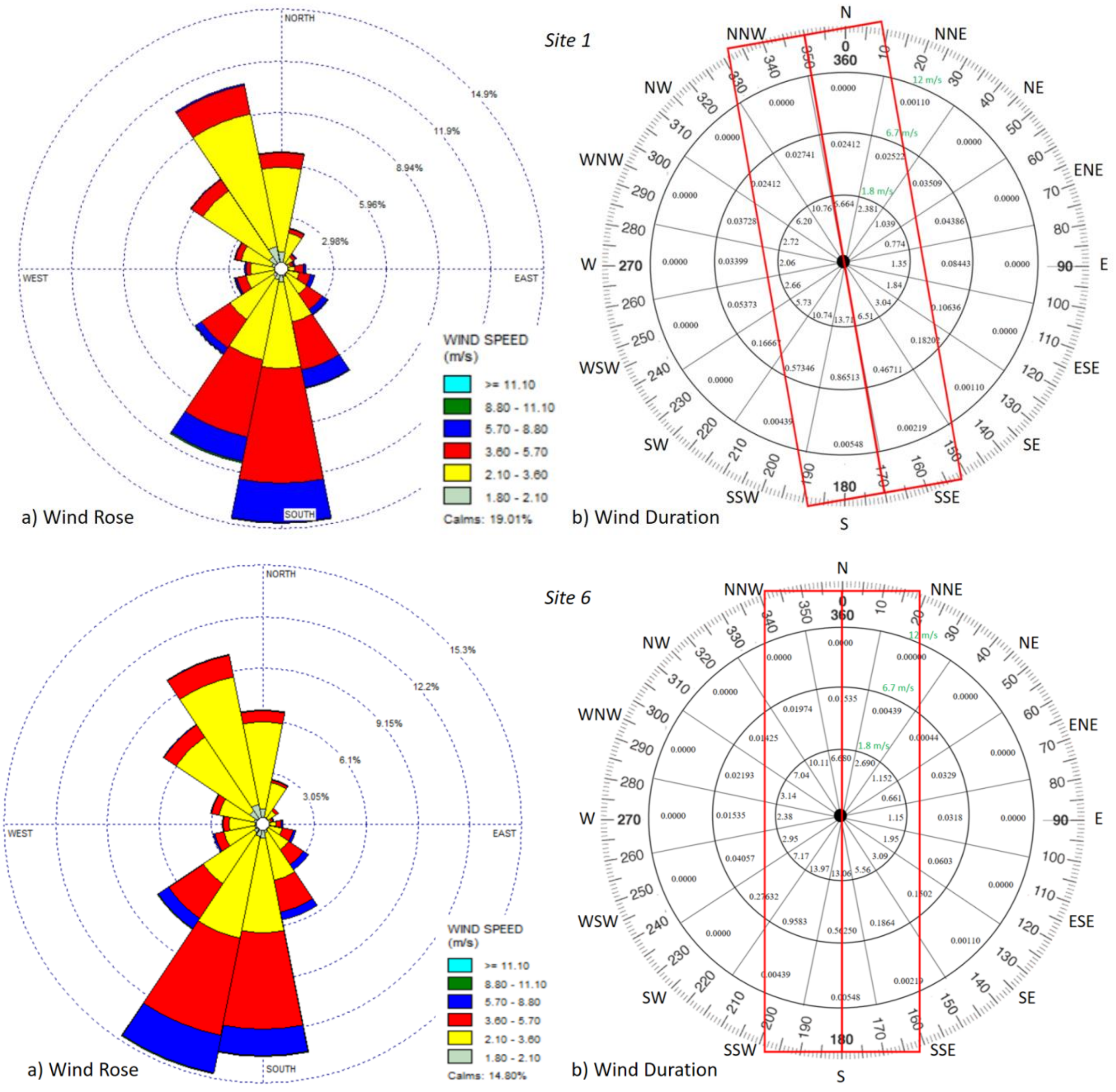

Figure 3. Wind Rose (Left Side) and Wind Duration diagrams for Candidate Sites 1 and 6.

Finally, a rectangular strip is traced over the centre of the circle and it has its breadth as twice the maximum persmissible crosswind component of the aircraft. The values falling inside this rectangular strip when overlayed is added up and this process is to be continued untill the maximum sum is obtained and that following direction should be along which the runway is to be constructed. In this process, the wind rose diagrams and wind duration diagrams were finally plotted as shown in Fig.3 for site 1 and 6. The red rectangular strip denotes the runway to be constructed at the respective candidate sites of the airport. For all candidate sites, a single runway was able to provide the minimum coverage required for flight operations. The calm period winds are also quite significant in all the candidate sites considered. The wind analysis successfully justified the direction of the runway making it feasible to plan the design of the airport. The analysis brought out six different candidate sites for the greenfield airport of Kolkata. The feasiility of airport construction in these sites is discussed below.

3. RESULTS AND DISCUSSIONS

It has been clearly described by Randy Murphy (2002) that, how Remote Sensing and Geographic Information Systems (GIS) can be used as a cost-effective method to share information between people such as airport managers and airport planners who are actively involved in facilitating infrastructure development and urban planning in and around the airports. In an earlier study GIS was used for the site selection of an alternative airport for the Griffin-Spalding County Airport (The LPA Group Aviation Consultants, 2009) which was constrained by encroachment. Different data layers such as state roads, population centre, land use, slope, streams, wetlands, etc. were analyzed using GIS and eight sites were selected for preliminary screening. These were then ranked based on additional factors such as infrastructure/land acquisition, constructability, operational capability, and environmental factors, unsuitable areas were eliminated from consideration and further study was conducted on the ideal sites selected for the airport. Similarly, in another study, GIS-based Multi-Criteria decision making was used (Mohsen et al., 2016) for the optimal site selection of airport which was crucial for developing countries where resources are meagre and data imperative to make rational decisions. Multi-criteria approach was used (Athanasios Ballis, 2003) for the selection of the site for the development of a new airport at the island of Samothraki. A three-stage approach was followed. Initially, factors such as land use, the existence of archaeological or historical sites and wind characteristics were considered to identify candidate sites. In the next stage, these sites were evaluated on the basis of socio-economic impacts due to the requisition of land and buildings and cost (airport construction and earthworks were analyzed to eliminate obstructions in the surroundings of the airport). Finally, the best alternative was chosen based on multiple factors such as interference with roads, hydraulic works, environmental impacts such as air-pollution and noise, expropriation, etc. GIS was used by Charles et al. (2011) for the analysis of the runway extension of Margaret Ekpo International Airport which is located in Calabar, Nigeria. Here, Landsat imagery was used for generation of the land use map of the region, Digital Elevation Model (DEM) was downloaded from the internet and these datasets were modified, processed and used in conjunction with geospatial applications such as ERDAS Imagine to carry out the analysis. The analysis dealt with factors such as environmental impacts (effects on huge costs involved and existing urban settlements), land use, economic benefits of the project, accessibility, pollution as well as safety and security issues. The investigation highlighted the role of GIS and other geospatial tools which are crucial in complex planning processes which if well utilized can enhance high cost cuts and uplift the economic benefits of the project. Irem Bahcelioglu (2014) used GIS to evaluate criteria for the site selection of a new airport for the historical city of Gaziantep in Turkey. The importance was given to factors such as slope, geology, hydrology, agriculture, roads and land use for the project. A maximum slope of 0-2% was considered permissible for construction purposes. A 1000 m buffer zone was created around hydrological areas such as rivers and that area was classified as restricted for airport construction. Minimum limit of approach from industrial areas was taken as 2500m and it was proposed that the new airport should be within 5000m reach from existing highways. Since residential areas were considered as historical areas, an approach distance of 1500m was applied and this came under the restricted category. A suitability map was prepared combining all these criteria and it was found that the most suitable areas fall on the north-east side of the city. The report also discussed the evaluation procedure of the site selection of the third airport for Istanbul.

Further to the above-mentioned studies, Transportation Associates (2015) depicted the use of MCE and GIS for the airport site selection for Sydney. Initially land was identified such that it is readily convertible to aviation uses by excluding industrial and urban areas, largely below a maximum slope required for runways, close to sources of demand for airport, ability to accommodate up to 4000m single runway, not limited by current air navigation constraints, travel distance up to 2 hrs, etc. The suitable areas were then analyzed on the basis of factors such as connectivity, development costs, commercial opportunities, noise impact, waterway and water supply, greenhouse gas emissions, distance from population centers; local air quality, flora/fauna species in the locality, national and state parks, heritage areas, flood risk, land contamination, risks, etc. and five preferred areas came up. These were subsequently ranked on additional criteria such as minimizing time to major road systems, flattest land available, local topography, ability to incorporate a cross runway, proximity to growth centres and commercial opportunities, mine subsidence, transportation network, etc. and a final set of suitable sites was proposed. Moreover, Weighted overlay and MCE have been also used for a wide variety of site suitability studies (Manish et al., 2013; Renzhi et al., 2014; Yerubapu, 2012; Nayama et al., 2016; Santosh et al., 2014; Tegou et al., 2009; Adam et al., 2014; Katie Moore, 2008; Michal et al., 2014; Michaela Bobeck, 2017; Aleksandar et al., 2013; Yuan et al., 2017; Aleksar et al., 2015; Hadeal et al., 2015; Mark Berube, 2014; Ahmed et al., 2017; Debishree et al., 2015; Habiba et al., 2018; Mohammad et al., 2014; Sehnaz et al., 2011; Demesouka et al., 2014; Pece et al., 2012).

Considering the above, in the present study, it is very important to understand the regional plan, airport use, proximity distance, ground accessibility, obstructions, noise nuisance, grading, drainage and soil characteristics, future development, availability of utilities, and the economic consideration of the candidate sites for an airport construction. The site under study should also form an integral part of the national network of airports in the country. During emergencies, it is also important to consider the proposed civilian airports are effectively used by the military for national defence and safety purposes. In addition, the airport site should not be located such that it is close to existing airports because this can lead to interference in aircraft movement patterns and this is not at all favourable. Among the candidate sites (Fig.2), site 3 faces this problem, since its approach zone coincides with that of the existing Netaji Subhas Chandra Bose International Airport. Also, the physical separation between the two is only about 12 km which makes it dangerous for simultaneous operations to happen in both airports because of huge volumes of air traffic that are expected. Thus, Site 3 was eliminated here from the list of candidate sites for the new airport as explained below.

Ground accessibility is considered because travel time by road is an important deciding factor, especially for short-haul operations. While landing and takeoff, an aircraft loses or gains altitude very slowly as compared to its forward speed. Due to this reason, it was absolutely necessary to have long clearance zones on either side of the runway known as approach zones over which an aircraft can safely gain or loose altitude. In addition to this, due consideration was taken to select a better site where the landing and takeoff paths of the aircraft pass over land which is free from industrial or residential areas due to noise pollution and other safety concerns. Grading, drainage and soil characteristics were also considered important for the construction and maintenance of airport which in turn can influence the site selection. The occurrence of floods also has been a due consideration and sites with high water tables need to be avoided due to the possibility of the requirement of costly subsoil drainage. It was also necessary to think of future development due to increasing air traffic. This is the reason why we selected candidate sites having enough area to accommodate at least 4 runways within the airport.

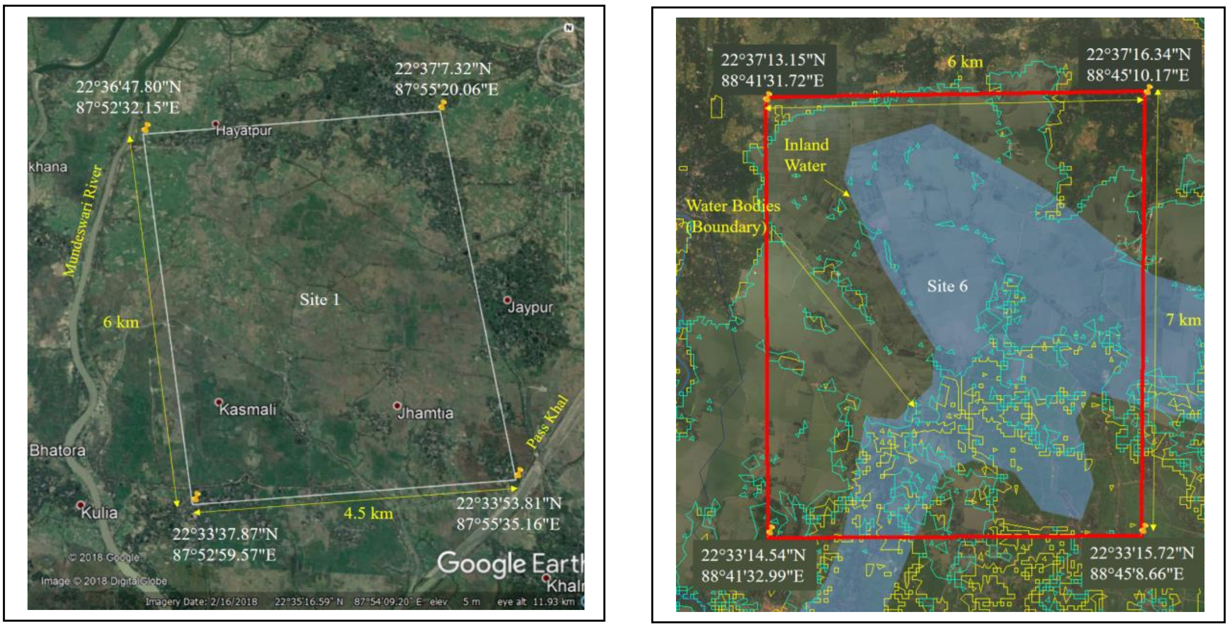

Figure 4. Maps of Site 1 (left) and 6 (right).

(i) Site 1: The proposed site 1 as shown in Fig.4 is rectangular (approximately 6.0x4.5 km) in shape and has an area of approximately 2760 hectares. It is oriented in the NbW-SbE (350^o-170^o) direction. *Physical Aspects:* The proposed site mainly consists of agricultural land whose land use primarily includes agriculture and settlement. The selection of this site would change the land for non-agricultural purposes. No major water body exists in the given area. However, seasonal ponds and a stream (seasonal) were identified from the topographical map of the region. The Mundeswari river passes at a distance of around 1km towards the east and there is the Pass Khal (canal) towards the south. The Amta-Palashpai road passes near the northern end of the site and the closest railway station is located at Amta which is nearly 9km away from the site. *Pollution Aspects:* The proposed site is mainly open land used for cultivation with the presence of scattered settlements. Since villagers mostly use fossil fuel for cooking, air and noise pollution are minimum at Site 1. Air quality influencing region for aircraft emissions is usually 1000 feet below and generally around 3km on either side of the runway. For Code 3 and 4 runways, the approach zone extends up to 3km on both sides of the runway and noise impacts due to mobile sources such as aircraft persists in this zone. Villages such as Chak Hayatpur, Mansuka, Par Kalahar, Narendrapur, Bhairabpur, Palashpai, Chanpanagari, Jhikhira and Ghardubra fall towards the northern side and Nignan, Khari Geria, Ajangachhi, Fatik Beria, Dhanyaghari, Hio and Khalna fall towards the southern side of the site. Noise impact on these settlements would be minimal during the operation phase of the project and these impacts can be successfully minimized with the implementation of best practices at the airport. Carrying out the Environmental Impact Assessment (EIA) is also additionally necessary before finalisation of the project. *Ecological Aspects:* Since the project is being built on agricultural land, major crops being cultivated and other trees of common species in the area are likely to be affected. Impact on the environment due to biomass loss can be compensated by afforestation. No national park and wildlife sanctuary exists within the project boundary and in a 10km radius of the project area. Hence, no appreciable impacts in this regard are anticipated. *Social Aspects:* The proposed project requires approximately 2760 acres of land and this means the displacement of nearly 10 villages namely: Khajur Daha, Jhamtia, Kasmali, Kamar Khola, Madhya Jaypur, Paschim Jaypur, Kalasdihi, Chak Janardan, Kakrol and Shibgachhia. The total number of households from these villages is approximately 5014 with a population of 23075 (from the Census of 2011). Another 10 villages would be partially affected. This would mean the loss of livelihoods for a large number of agricultural families who would have to be displaced from the proposed site. This would also affect infrastructure and social relationship among these people. *Historical Resources:* No historical and archaeological sites are located within the project boundary. Proper reconnaissance survey would have to be carried out at the proposed site and Lidar data would also need to be collected to assess the obstruction free zone on either side of each runway.

(ii) Site 2: This site (Fig.2) is also rectangular (approximately 6x5 km) in shape and has an area of approximately 3120 hectares. It is oriented in the N-S (357º-177º) direction. *Physical Aspects:* Site 2 consists mostly of agricultural land. Other land use includes commercial based small-scale factories and industries. No major water body exists in the area; however few seasonal ponds, a perennial stream and the Saraswati Khal canal were identified. The Howrah-Bargachia-Amta road and a railroad of the Indian Railways passes through the centre of this site. They will have to be relocated or an underground tunnel would have to be constructed for transportation. *Pollution Aspects:* The site contains open land most parts of which is being used for agricultural cultivation. There are small factories and industries within the proposed site such as Creative Polypack Ltd, Ajit Hazra Industrial Park, Sree Maa Sarada Ores and Forging India Ltd, SB Engineering Works, GRW Pumps Private Ltd, and Echo Gases Factory which need to be relocated. EIA is for this site too is mandatory. Villages such as Dudhkomra, Chak Bangla, Ichhapasar, Bade Sola, Haripur, Baghati, Singjor, Bhagabatipur, Nawabpur, Radhaballabhpur, Alipur and Anantarampur are present in the northern side of the site and; Jamdanda, Oadipur, Keshabpur Pal Para, Khasjalalsi and Boharia, fall on the southern side of the runway (approach funnel). *Ecological Aspects:* Crops and common species in the area are likely to be affected. No national park and wildlife sanctuary exists within the project boundary and in 10km radius of the project area. Hence, no appreciable impacts are anticipated. *Social Aspects:* The proposed project requires approximately 3120 acres of land and this means displacement of nearly 6 villages such as Baigachhi, Dakshin Santoshpur, Chak Mahishjol, Mahishgote, Uttar Santoshpur and Kanaidanga. The total number of households from these villages is approximately 3714 with a population of 23075 (from the Census of 2011). Another 12 villages would also be partially affected. This would mean, a loss of livelihoods for a large number of agricultural families who would have have to be displaced from this site. It would also affect infrastructure and social relationship among these people. *Historical Resources:* No historical and archaeological sites are located within the project boundary. Proper reconnaissance survey would have to be carried out at the proposed site and the Lidar measurements would also need to be available to assess the obstruction free zone on either side of each runway.

(iii) Site 3: The proposed site as shown earlier in Fig.2 is square (approximately 6x6 km) in shape and has an area of approximately 3690 hectares. It is oriented in the N-S (4º-184 º) direction. However, as indicated earlier, Site 3 has been eliminated from consideration due to its close proximity to NSCB airport.

(iv) Site 4: Site 4 is almost a parallelogram (approximately 6x6 km) in shape and has an area of approximately 3460 hectares. It is oriented in the NbE-SbW (12º-192º) direction. *Physical Aspects:* This site also mostly consists of agricultural land whose land use includes agriculture and settlement. The selection of this site would change the land for non-agricultural purposes. No major water body exists in the given area; however seasonal ponds were identified from the topographical map of the region. Road connectivity is good and a railroad of the Indian Railways passes just below the site at a distance of nearly 500 metres. *Pollution Aspects:* The proposed site mostly contains open land used for agricultural cultivation and settlement purpose. There are several factories and industries towards the northern and western end of the site falling within a 10km radius of the site. Villages such as Jhungri, Shaksahar, Balipur, Bazarati, Chak Bhika, Dara, Bangoda, Amreswar, Karunarhati, Kashia Danga, Taldighi, Madhabpur, and Hogaldara are present in the northern side and Solgohalia, Kalaria, Gaur Daha, Sri Krishnapur, Karkhanar Chak, Makhal Tala and Banamalipur, fall towards the southern side of the site (inside the approach funnel of the runway). *Ecological Aspects:* Crops and common species in the area are likely to be affected. No national park and wildlife sanctuary exists within the project boundary and in 10km radius of the project area. Hence, no appreciable impacts are anticipated. *Social Aspects:* The proposed project requires approximately 3460 acres of land and this would displace nearly 13 villages namely: Kamar Hati, Kasinagar, Bausahar, Kashinathpur, Jalalabad, Satbaria, Mathurapur, Garanbaria, Sangur, Dakshin Kasipur, Nabhasan, Makrampur, and Raypur. The total number of households from these villages is approximately 7837 with a population of 36888 (from the Census of 2011). Another 15 villages would be partially affected. This would have a huge impact on a large number of agricultural families who would have to be displaced from the proposed site. This would also affect infrastructure and social relationship among these people. *Historical Resources:* No historical and archaeological sites are located within the project boundary. Proper reconnaissance survey would have to be carried out at the proposed site and Lidar data would be also necessary to assess the obstruction free zone on either side of each runway.

(v) Site 5: This site is rectangular (approximately 6.5x5.0 km) in shape and has an area of approximately 3370 hectares. It is oriented in the NbW-SbE (350º-170º) direction. Both sites 5 and 6 are similar in the respect that most parts of these two sites are covered by water bodies that fall under the wetland category. Hence, various aspects of Site 5 may be seen from the discussion below for ***Site 6.***

(vi) Site 6: The proposed site 6 as in Fig.4 is rectangular (approximately 7x6 km) in shape and has an area of approximately 4580 hectares. It is oriented in the N-S (0º-180º) direction. As stated above, both sites 5 and 6 are similar, fall under the wetland category. Wetlands are areas where water covers the soil or is present either at or near the surface of the soil all through the year or for varying periods of time during the different seasons of the year. They have several benefits like wildlife nursery, flood control, pollution filter, storm buffer, wind buffer, fertile farmland, recreation, tourism, carbon sink, jobs hub and sea level rise mitigation. The wetlands in both sites are not listed as Ramsar Sites and hence are not protected by any international law. For airport construction, these wetlands have to be converted to land suitable for construction. They are a fragile ecosystem and are vital to the health of all other biomes and to wildlife and humans everywhere. Thus, different ecological factors must be taken into consideration while carrying out the EIA and reconnaissance survey before their conversion. Newer rules facilitate the development of wetlands as real estate, industrial sites and garbage dumps and thus both candidate sites have great potential to be developed as a greenfield airport.

4. CONCLUSION

This paper successfully demonstrates the use of GIS and Remote Sensing techniques to find candidate sites for the construction of a Greenfield Airport for Kolkata, India. Authors have investigated site suitability of five candidate sites out of six (proposed for analysis) that satisfied various criteria in different ways. A complete investigation of these sites for the construction of a Greenfield Airport was certainly a complicated process which required an understanding of various subjects and expertise. A typical investigation would consider several factors such as land use planning, socio-economic impact, regional planning, wind and weather conditions, operational and safety aspects, construction costs, road and air connectivity, etc. This study may be regarded as one of the preliminary investigations for Kolkata and emphasizes that Multi-criteria evaluation is an appropriate method to find such suitable areas based on the given factors.

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