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THE USE OF VECTOR-BASED GIS BOOLEAN ANALYSIS TECHNIQUE TO DETERMINE THE BEST LOCATION FOR A MUNICIPAL SOLID WASTE LANDFILL SITE IN MAFRAQ GOVERNORATE/ JORDAN

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Abstract: The choice of location for a landfill site has a significant effect on the economy, ecology and overall environmental well-being, and is therefore a vital decision in the process of city planning. In Mafraq, the huge increases in population, as a result both of the arrival of significant numbers of Syrian refugees, as well as an increasing birth rate, has increased the pressure on the limited resources available, as well as emphasising the necessity of building a proper system of waste management, as well as a well-located landfill site. In relation to the latter, the aim is to position it so as to minimise any negative impact on either the environment or on public health. In terms of GIS, vector analysis tools and multi-criteria decision analysis (MCDA) were applied to ascertain the best location for a landfill site. The aspects that were assessed in this research included slopes, roads, airport, wells, soil, faults, international borders, Wadis, and urban areas. The weighting given to each item was determined using the Boolean technique in terms of its importance to the location of a landfill site. The conclusions indicated that 18 sites in the area researched were potentially suitable for landfill sites, but that the Jordanian government had to undertake further work using the results of the GIS research to determine where the site should be located.

Keywords: Jordan; Mafraq;Landfill; GIS; Multi-criteria evaluation (MCE)

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INTRODUCTION

The longest running form of waste management is landfill, which is the burial of waste materials. The choice of where a landfill site should be located is dependent on many different elements, laws and rules and, as such, a significant amount of information needs to be assessed in making the decision. As noted by Baban and Flannagan (1998) and Allen *et al*. (2002), GIS is most often used to determine appropriate sites and overcome the challenge of so many competing issues. As Chang *et al* (2008) said, the economic, environmental and societal factors used depend on the views of specialists and an examination of the different literature available. These different elements are important in determining the location of the site because landfill may influence the biophysical environment and the water available in the surrounding places, as explained by Siddiqui *et al*. (1996), Kontos *et al*. (2003) and Erkut and Moran (1991). Other factors that must be considered in the choice of site include the costs connected with satisfying the criteria, the development of management and the overseeing of the sites, as examined by Delgado *et al*. (2008), Erkut and Moran (1991), Kontos*et et al*. (2003) and Lober (1995).

A World Bank visibility study from 2004 demonstrated the significant increases in the production of Municipal Solid Waste (MSW) that was predicted to occur; from an estimate of 1.46 million tonnes per year, it was expected to reach 2.5 million tonnes by 2015, with 0.9 kg/capita/day being generated. Economic and cultural developments have meant a higher standard of living and a corresponding increase in MSW. As noted by Aljaradin and Persson (2010), this increase has not yet been matched with effective practices in terms of landfilling, which itself presents problems for the environment and the health of the population.

As Aljaradin and Persson (2010) observed, out of the 24 landfills in Jordan, only one is made for sanitary products, whilst the others lack even the basic requirements that are needed.

As variously pointed out by Kontos *et al*. (2003), Sarptas *et al*. (2005), Sener *et al*. (2006), Gomez-Delgado & Tarantolak (2006), Delgado *et al*. (2008) and Chang *et al.* (2008), GIS methodology permits a mixture of different assets and spatial calculation. Given that the decision as to where to locate landfill sites requires information with a spatial element, a GIS approach has been most often used in the recent past.

The so-called multi-criteria decision analysis (MCDA) is used when complicated information needs to be assessed by those charged with making decisions. As explained by Malczewski (1997), this approach divides the issues into smaller parts and assesses each aspect separately before combining them logically. Sener et. al. (2006) observed that combining GIS and MCDA is ideal for choosing landfill sites because GIS offers appropriate maneuvering and organizing of the information, whilst MCDA correctly combines the different yardsticks that are used in choosing appropriate sites for landfill.

GIS and MCDA have often been chosen for site selection in many different applications including landfill, water-harvesting schemes and infrastructure projects. Many examples can be found in literature, as extrapolated by Al-Adamatet *et al*. (2017), Al-Amoush *et al*. (2016), Al-Shabeeb *et al*. (2016), Al-Shabeeb, (2016), Al-Shabeeb (2015), Al-Adamat, (2012), Şener*et al*. (2010), Sener*et et al*. (2010), Guiqin *et al*. (2009), Sumathi & Sarkar (2008), Zamorano *et al*. (2008), Chang *et al*. (2008), Akbari *et al.* (2008), Nas *et al*. (2008), Mahini & Gholamalifard (2006), Sener *et al*. (2006), Kontos *et al*. (2005), Vatalis & Manoliadis, (2002), and Siddiqui *et al*. (1996).

Many conditions must be linked in deciding where to position landfill sites. The GIS is appropriate for handling this because of its appropriateness for dealing with and assessing copious quantities of spatial information from different places, as noted by Sener *et al.* (2006). The use of GIS in establishing possible landfill sites has been the subject of a great deal of research, from Akin (2012), Nas *et al. (*2010), Şener *et al*. (2010), Sumathi & Sarkar (2008), Zamorano *et al.* (2008), Sadek *et al.* (2001), Leao *et al*. (2001), Sarah & Susan (2000), Lin & Kao (1998), Charnpratheep *et al*. (1997), Kao *et al*. (1996), Muttiah *et al*. (1996) and Kao (1996).

This paper shall apply the vector analysis technique in choosing the best site for landfill in the Mafraq Governorate, and nine physical and economic measures will be applied, including, faults, slope, soil, urban, airport, international border, wells, wadis and roads.

Study Area

As shown in **Fig. 1**, the area being studied comprises a total of 26,276 km^2 , and is based in the northern part of Jordan. It has more than 1 million inhabitants (DOS, 2015) and the area typically experiences hot and dry summers as well as cold winters. As shown in **Fig. 2**, the percentage of clay in the soil covers a range from 15% in the east to 29% in the west. This diagram also shows the variations in rainfall; from 50mm in the north-west to 300mm in the central and south-eastern part of the area being studied. The topography of the area has high levels of elevation (1224 m) in the north-west, and low levels (391 m) in the central and south-eastern areas (**Fig. 2**). In the western area, the surface water flows towards the south-west, whereas, in the eastern areas, it flows towards the north-west (**Fig. 2**).

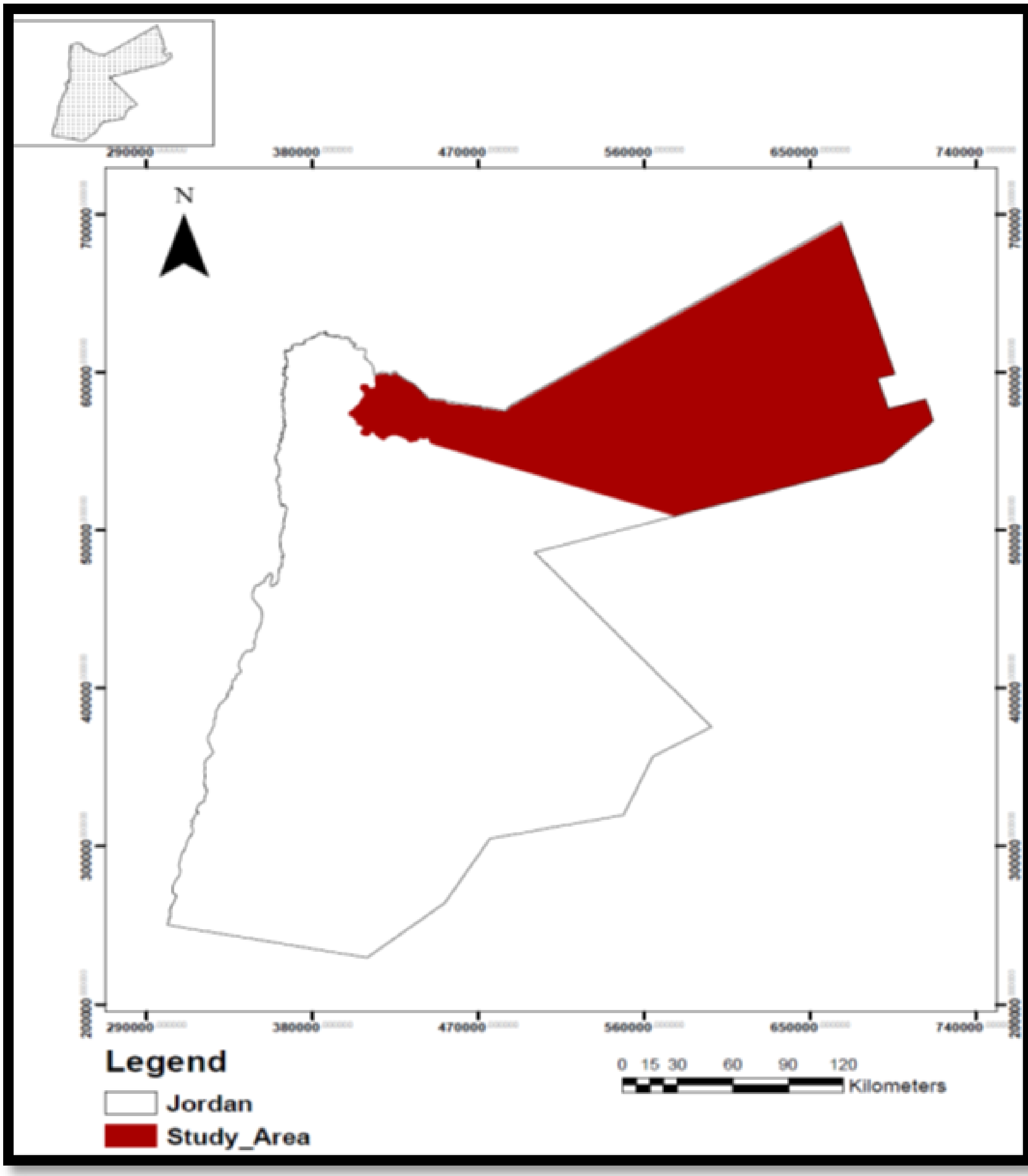

Fig. 1 Study area location within Jordan

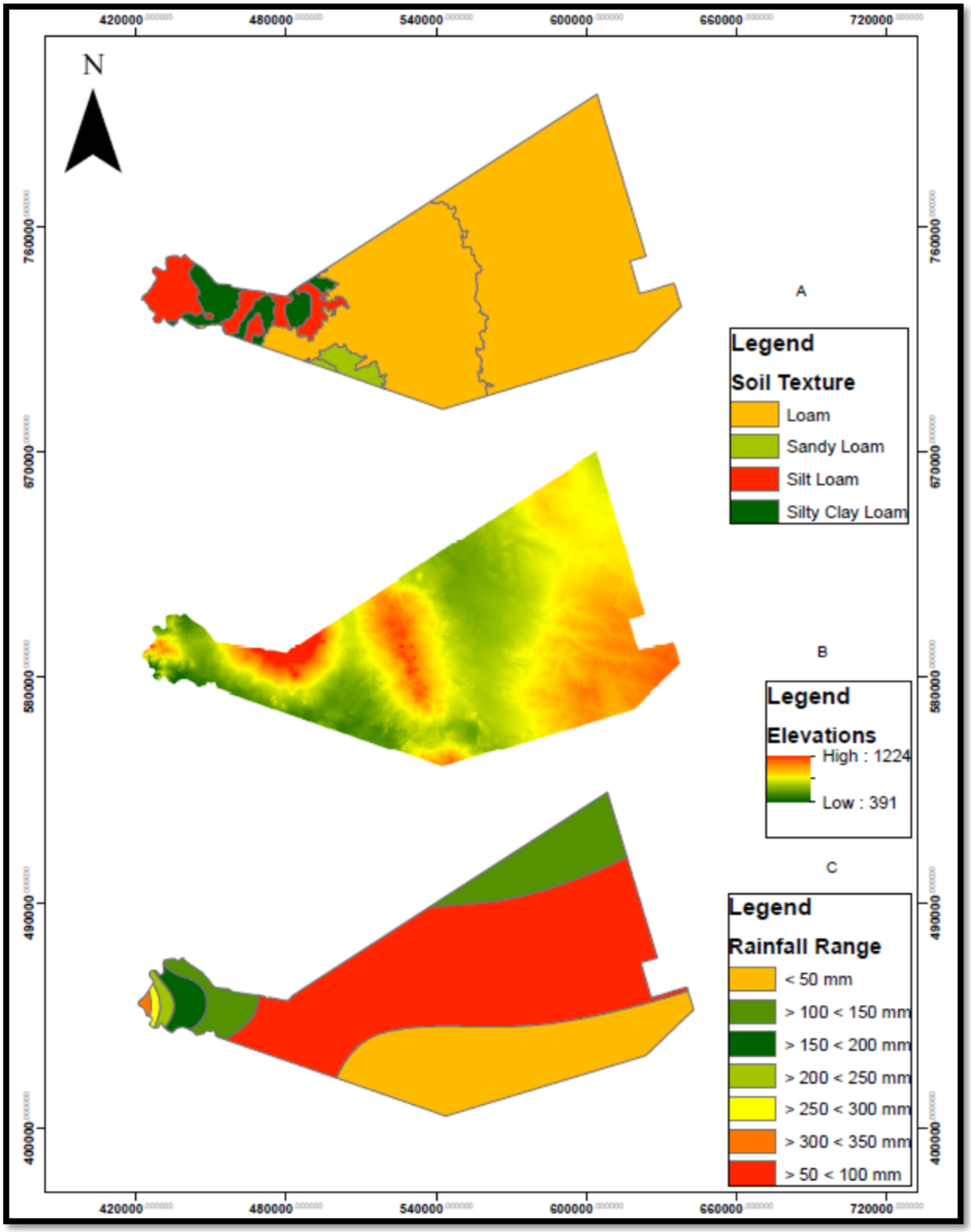

Fig. 2 Soil texture (A), Elevation(B) and Rainfall (C) of Study area

Fig. 3 Dumping the waste at Mafraq Landfill

Each day, there is an average of roughly 120 tonnes of waste collection, which means 43,800 tonnes of waste annually. According to Aljaradin & Persson. (2010), there is 1.2 kg/capita/day of municipal waste, and, at present, landfilling in Jordan involves the waste being left in trenches or cells, being evened out and pressed by compactors to reduce the space the different layers take, and then, as shown in **Fig. 3**, the waste being covered in soil.

As set out by Aljaradin and Persson (2010), the Mafraq landfill is based on a geological fault and it is a danger to the groundwater aquifer. In addition, the landfill produces unpleasant odours for travellers passing nearby.

Methodology

Site Selection Criteria

The approach taken in this research was designed by Al-Adamat *et al*. (2017). The measures applied were derived from a review of the literature, as set out in the introduction. The ratings for the various benchmarks are listed in **Table 1** and include Faults, Slope, Soil, Urban areas, Airports, International Borders, Wells, Wadis and Roads.

Table 1. Rating for the maps used in the landfill site selection

Map	Suitable (1)	Non Suitable (0)
Faults	>1000 m	<1000m
Soil	Clay>24%	Clay <24%
Airport	>10km	<10km
Slope	<=4%	>4%
Roads	>=500m, <=10000m	<500m, >10000m
International Border	>10 km	<=10km
Wells	>500m	>500m
Wadis	>500m	<500m
Urban	>5km	<5km

Data collection

In terms of identifying appropriate sites for the landfill projects, the main conclusions of this research, as shown in **Table 2**, were deduced using GIS layers provided by varying Jordanian government agencies, as well as other research. As shown in **Table 1**, several sources of information were accessed to produce the nine themed maps used in this research. The slope map was created by using a digital elevation model (DEM) of the Shuttle Radar Topographic Mission (SRTM), which was acquired from the United States Geological Survey (USGS). In addition, maps of Faults, Airport, Wadis,

Table 2. Secondary and primary data used in this research.

Type of data	Scale/ Resolution	Data Format	Generated layers	Source
Faults	1:250,000	Vector	Lithology map	NRA
Soil	1:750,000	Vector	Clay Percentage	Previous researches
Airport	:250,000	Vector	Airport map	RJGC
Slope	30 m SRTM DEM	Raster	Slope map	USGS
Wadis	1:250,000	Vector	Wadis map	RJGC
International Border	1:250,000	Vector	International Border	RJGC
Wells	1:250,000	Vector	Wells map	WAJ
Roads	1:250,000	Vector	Roads map	RJGC
Urban	1:250,000	Vector	Urban map	RJGC

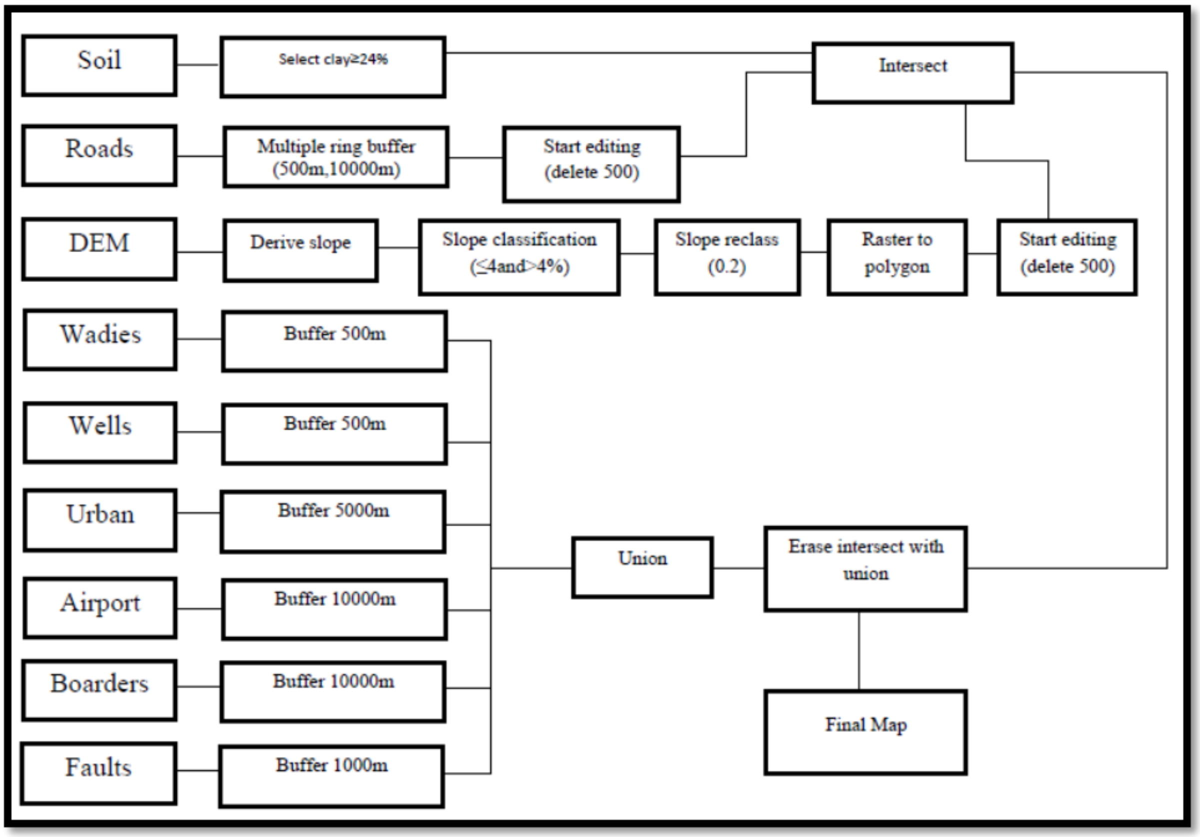

Fig. 4 Flowchart of the methodology followed in the study

International borders and Wells, to the scale of 1:250,000 were given by the Natural Resources Authority of Jordan (NRA), the Royal Jordanian Geographic Centre (RJGC) and the Water Authority of Jordan (WAJ). The soil map and corresponding information were taken from earlier research (Al-Adamat*et al*, (2007), and Batjes, *et al*. (2003).

Data Analysis and Results

This research used the vector GIS analysis method to apply the Boolean system. The flowchart set out in **Fig. 4** illustrates the approach used in choosing the most appropriate sites for landfill in the geographical area assessed. The key aspects used in this research include the following:

- Wadis, International borders, Faults, Urban and Airport were protected using the distances set out in **Table 1**.
- Roads were protected using the buffer distances given in **Table 1**. The table of the resulting layers was updated using the values listed in Table 1 (the 0 and 1 were added for each layer)
- The slope map was taken from the SRTM DEM (raster), and the slope was divided into <= 4% (suitable) and > 4% (unsuitable) based on **Table 1** and then converted into vector format.

- The slope map was organised according to Table (1) by adding a new field into its database that has suitable (1) and unsuitable values (0).
- The intersection command was used in relation to soil, roads and slope layers after choosing the suitable (1) areas in each layer.
- The Union command was applied to the remaining buffered layers.
- The Erase command was then used to remove the unsuitable areas from the final map (the union layers was used to erase the intersected layers)
- The suitable sites were subjected to the selection command to select the suitable areas with areas of more than 10 ha (100,000 m^2).
- The final map was converted to a point layer that represents the middle of each suitable area.

The aptness of road maps of the area being studied, buffer zones near roads and the suitability of the road maps are shown in **Fig. 5**. A landfill site needs to be located at least 500m away from major highways and city streets, but, equally, it must not be too far away from current road networks, so as to limit extra construction costs.

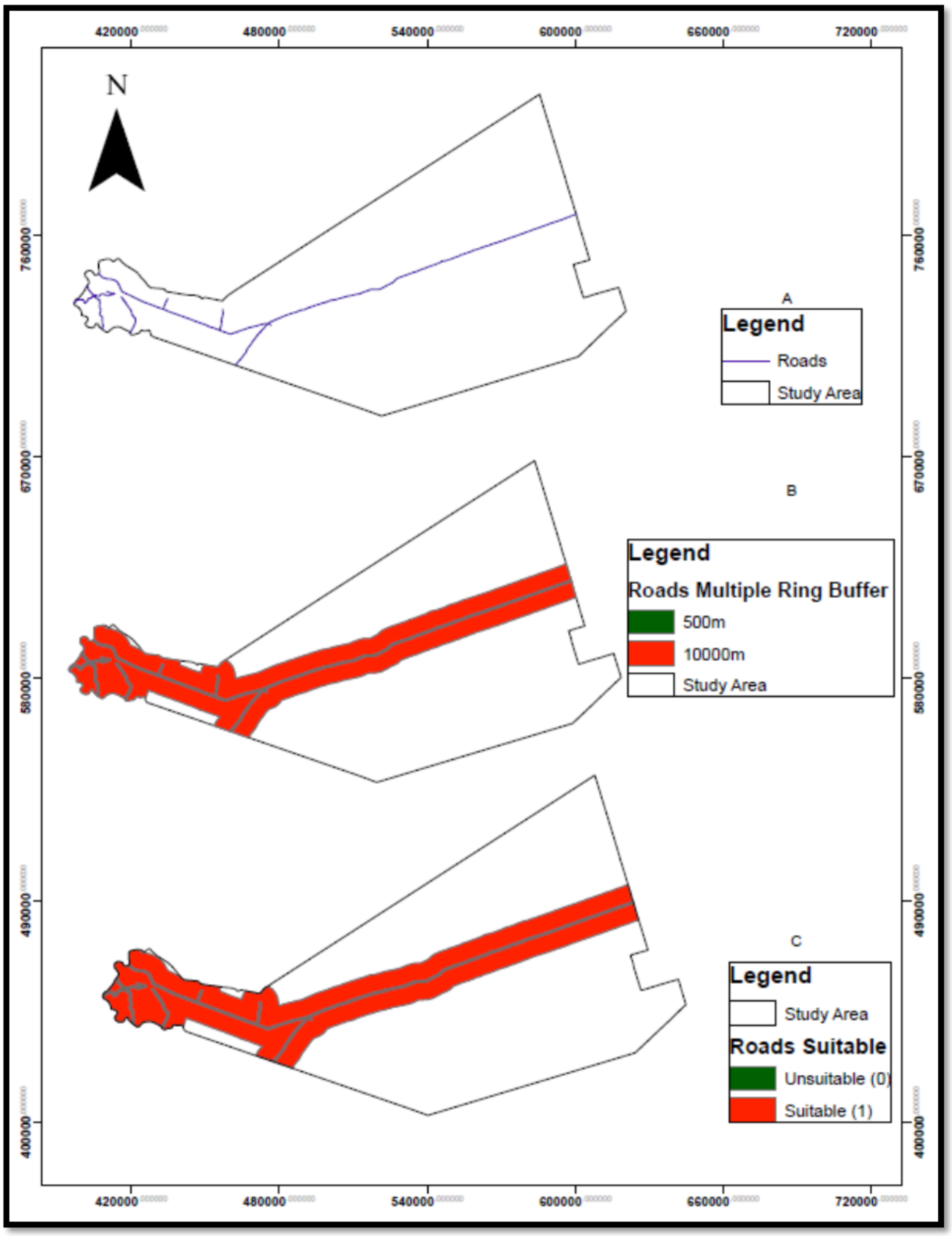

Fig. 5 Roads maps of study area(A), Buffer zones determined around roads(B) and Roads map suitability (C)

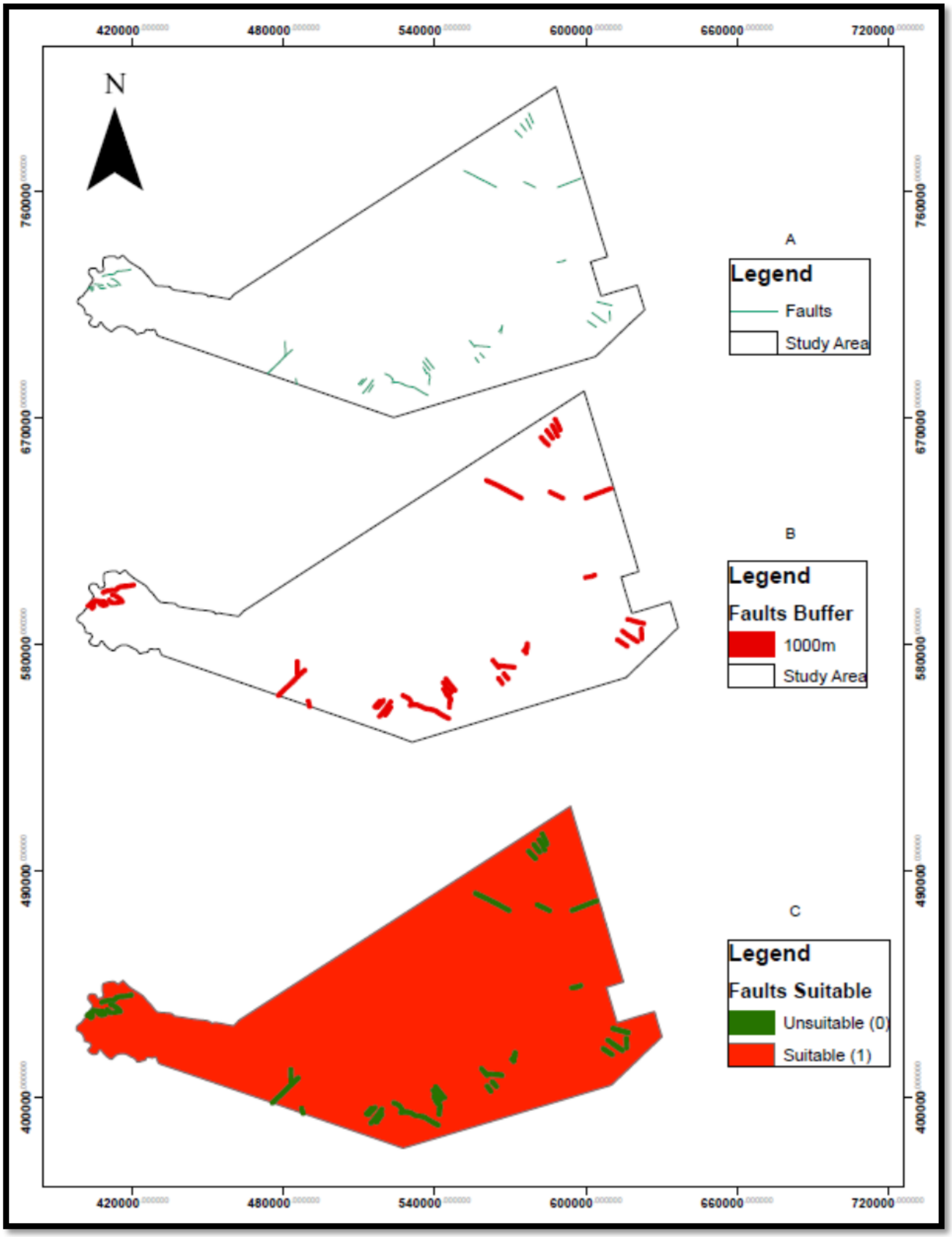

Fig. 6 Faults mapof study area(A), buffer zones determined forfaults (B) and faults map suitability (C)

The faults map for the area being studied, as well as the buffer zones for faults and the faults map suitability are shown in **Fig. 6**. Given that fault zones are leaky and porous, and are able to spread pollution or unclean agents, a landfill site cannot be located close to any faults and cracks. Therefore, closeness to faults was a significant factor in assessing the location of landfill sites. As noted by Dorhofer and Siebert (1998), landfills produce leachate that render them unsuitable to be located close to groundwater. Therefore, a buffer of 1000m will be placed around all fault zones using the technology in GIS software.

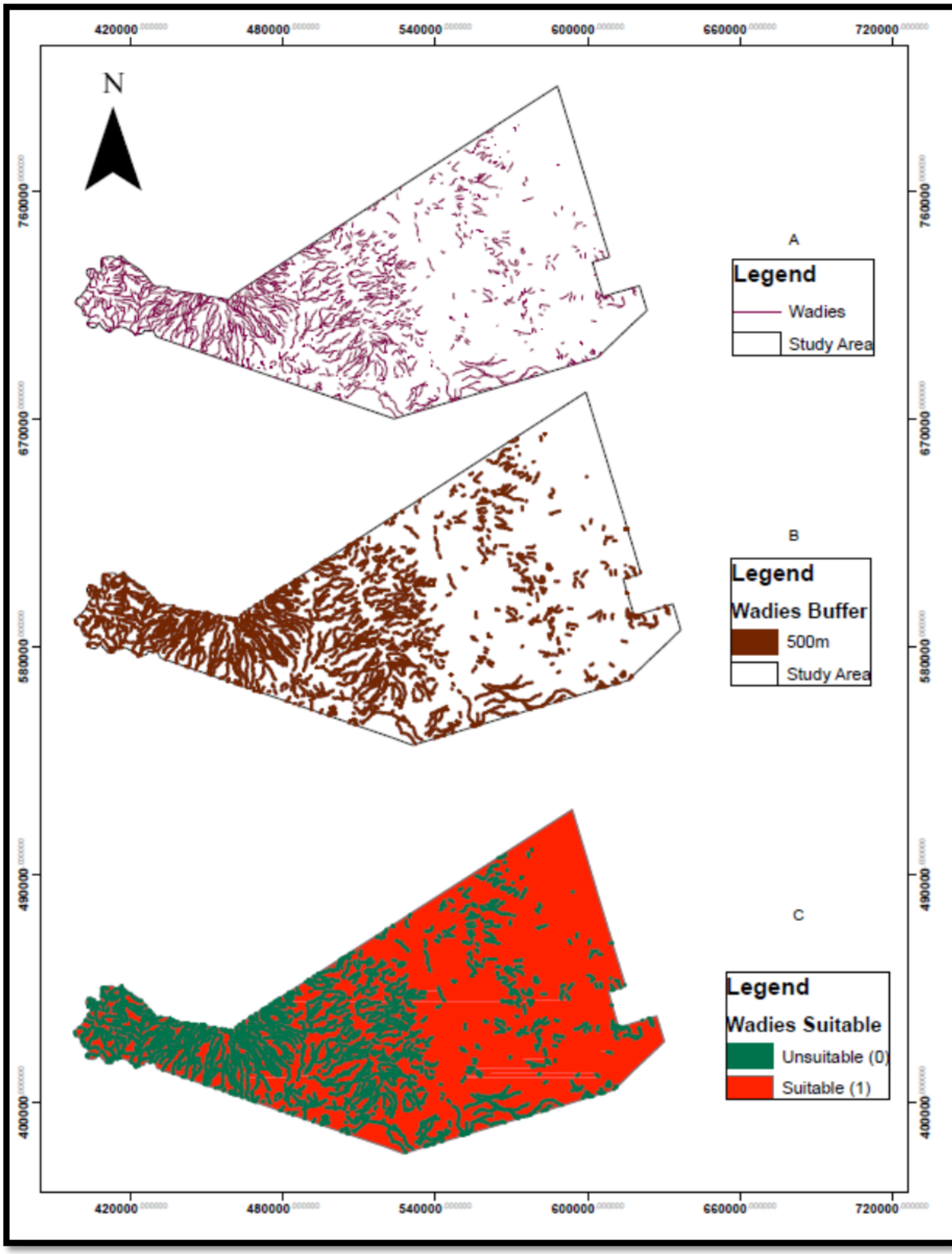

Fig. 7 Wadis map of study area (A), Buffer zones determined forwadis (B) and Surface water map suitability (C)

The Wadis map of the area being studied as well as the buffer zones for Wadis and the surface water map suitability are set out in **Fig. 7**. As noted by Dorhofer and Siebert (1998), landfills produce poisonous gases and leachate. This means landfills must not be sited near any surface streams and, in terms of this research, their closeness to Wadies was an important factor in determining possible landfill sites. Thus, a buffer of 500m will be placed using the GIS software technology to create a buffer around all Wadis.

The international border map of the area studied, as well as the buffer zones around international borders and the international border map suitability are depicted in **Fig. 8**. Given the importance of international border considerations, landfills must be located at least 10,000m away from any international border. However, it should also not be based too far away from international borders to avoid issues with bordering countries because of leakage from solid and liquid wastes.

Figure 9 shows the DEM of study area, slope classification and slope map suitability. The most suitable slope for building a landfill site is roughly 4%, as explained by Lin and Kao (1998, 2005). If slopes are higher than 4%, they are difficult to build and maintain, and they would produce higher runoff rates from rain. This leads to a lower infiltration which means contaminants can travel larger distances from their area and means a bigger area will be exposed to harmful chemicals produced by the leachate in the landfill. If, on the other hand, the slope is too low, this would affect the runoff drainage. In the area researched, the slope is deemed to be too flat and a weighting of 1 is taken if <= 4% slope and 0 if > 4% slope Allen *et al*. (2003).

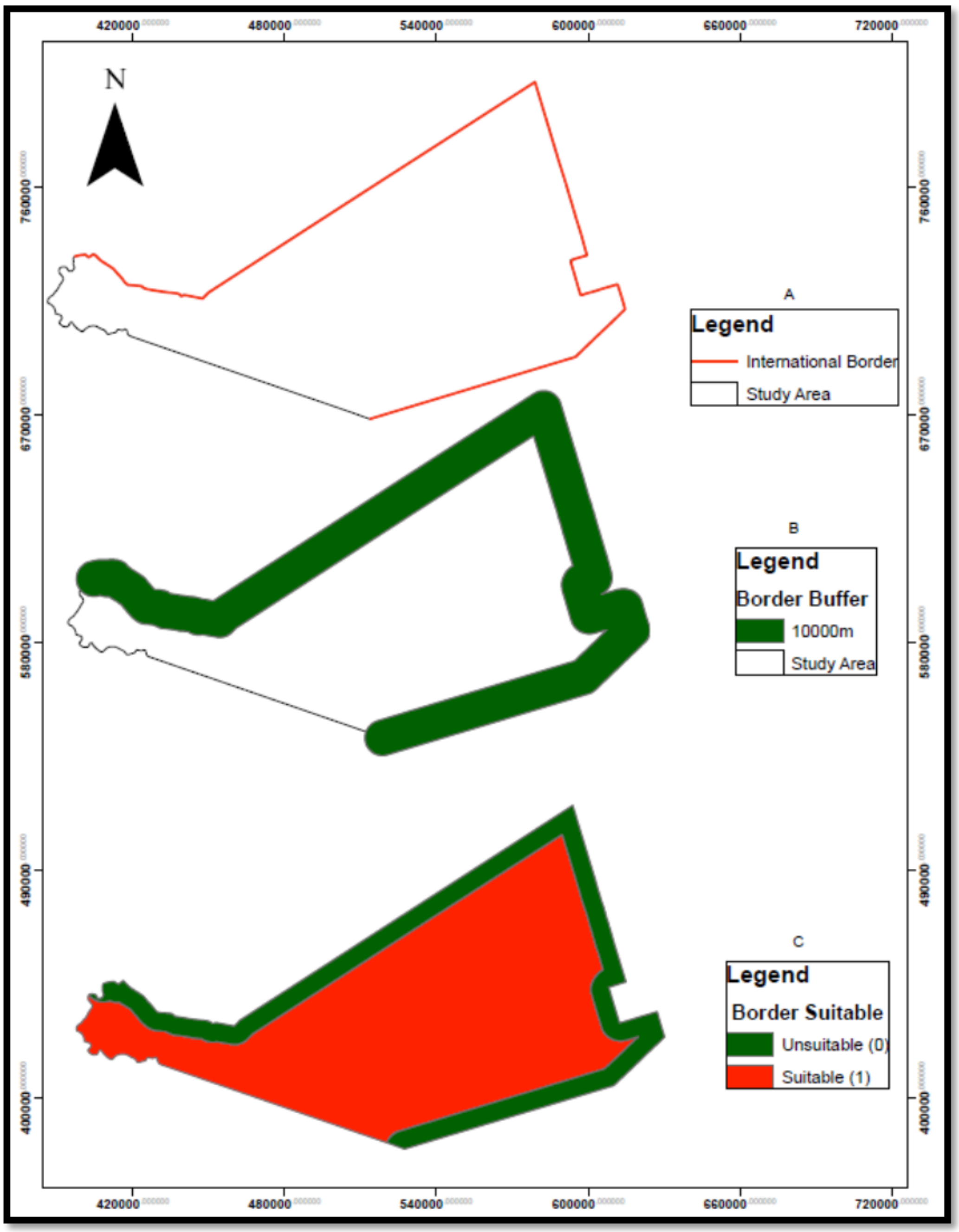

Fig. 8 International Border map of study area (A),Buffer zones determined aroundinternational Border (B) and international Border map suitability (C)

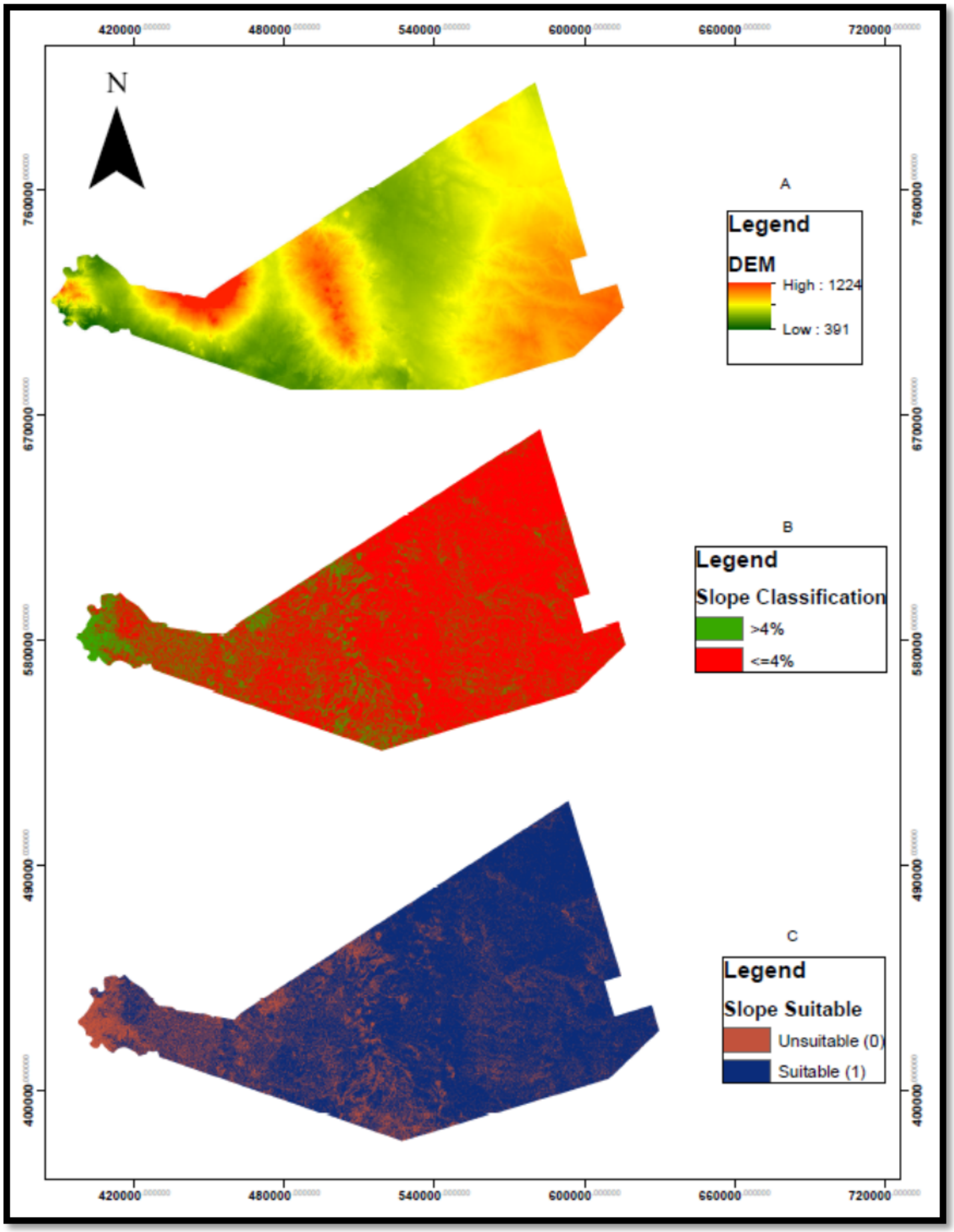

Fig. 9 DEM of the study area (A), slope classification (B) and slope map suitability (C)

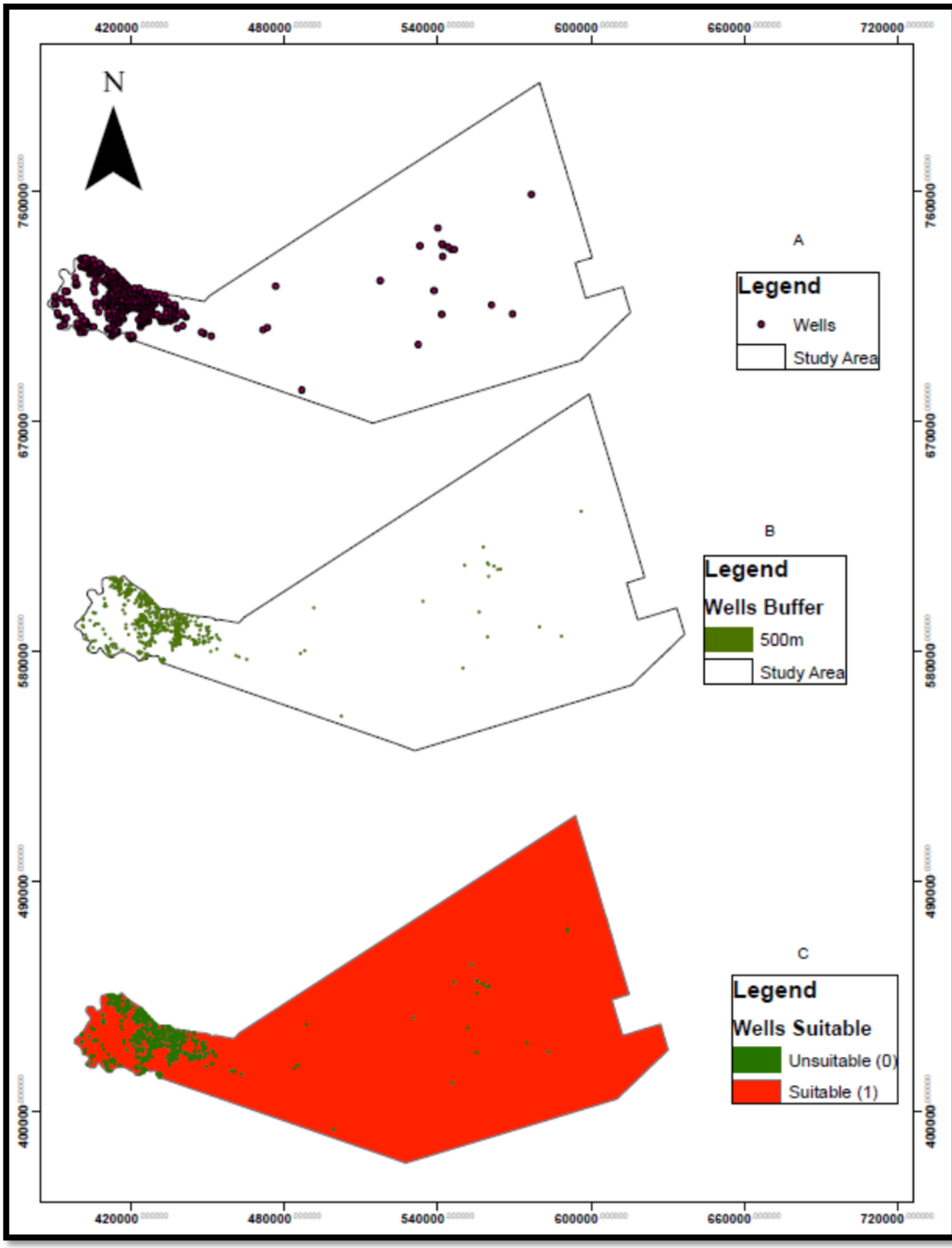

Fig. 10 Wells map of study area (A), Buffer zones determined around wells (B) and wells map suitability (C)

The wells map of the area researched, buffer zones around wells and wells map suitability are depicted in **Fig. 10**. Given that landfills produce poisonous gases and leachate, it is not appropriate for them to be close to water wells, as explained by Dorhofer and Siebert (1998). Proximity to wells was an important factor in assessing where landfill sites should be based and, for this reason, a 500m buffer will be placed around each well.

Figure 11 illustrates the airports map of the area researched, the buffer zones around airports and the airport map suitability. As Kontos*et al*. (2003) observed, international convention decrees that landfill sites must be based at least 10km from airports (Military and Civilian airports). A buffer zone of 10km was utilised for this research.

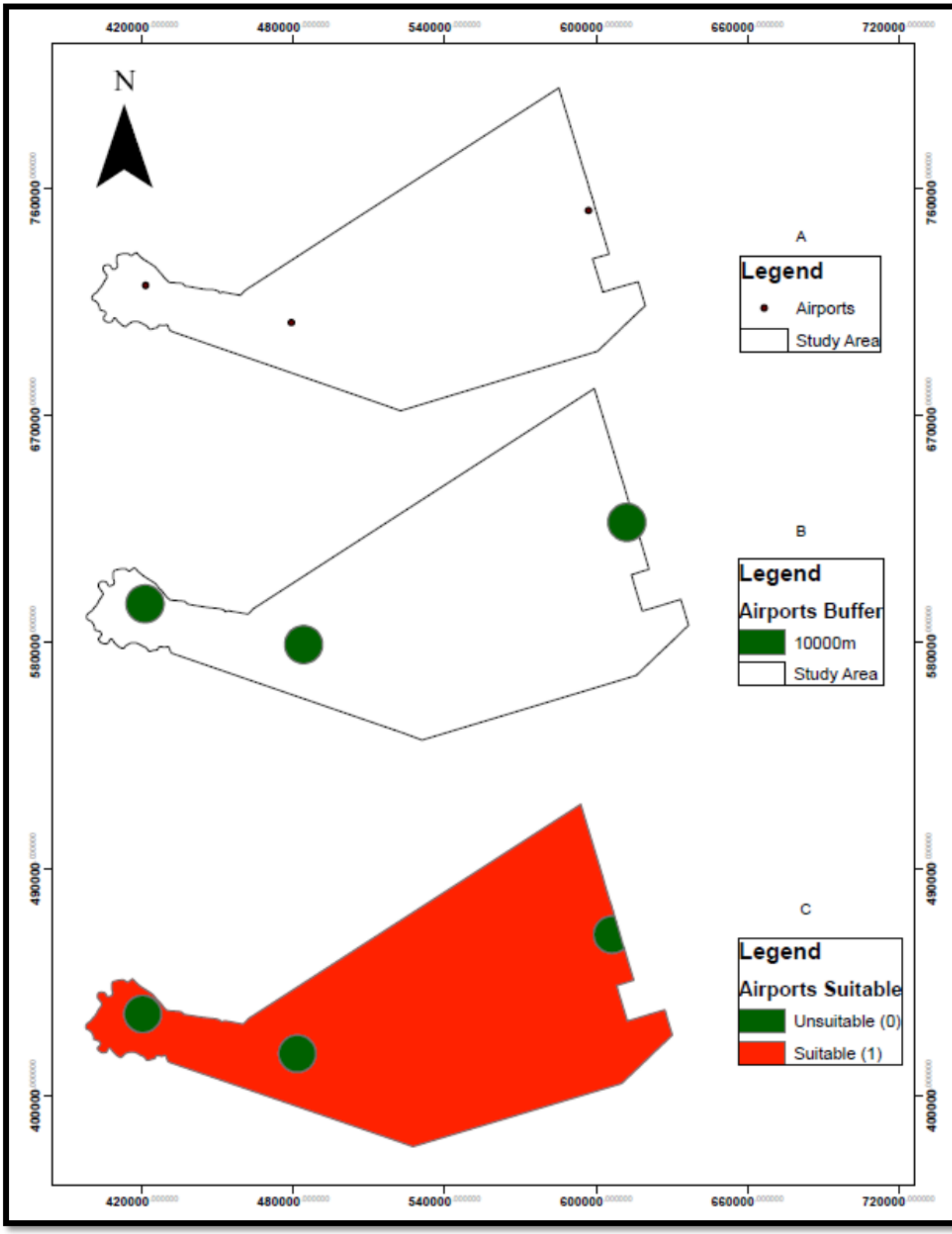

Fig. 11 Airports map of study area (A), Buffer zones determined around Airports (B) and Airports map suitability (C)

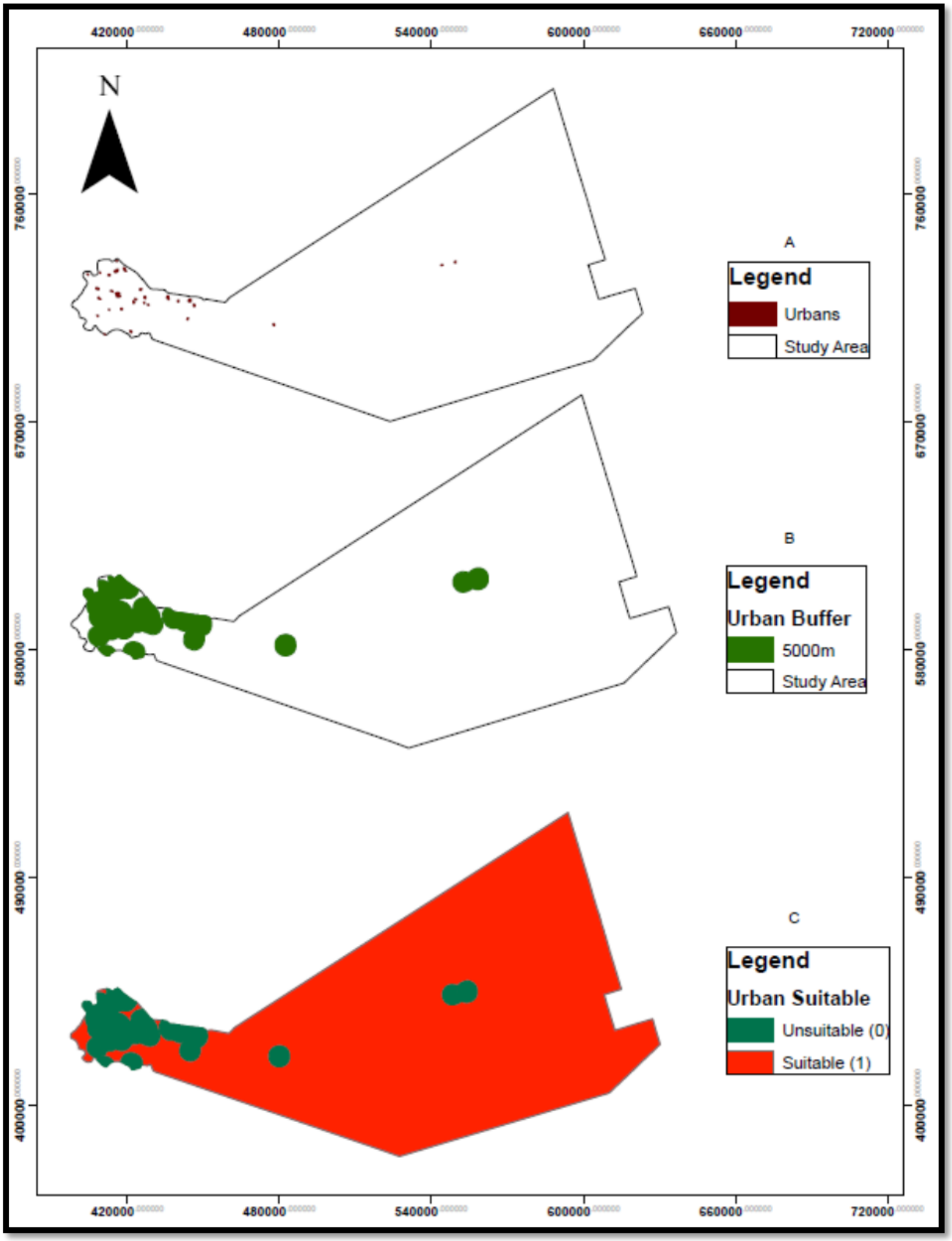

Fig. 12 Urban map of study area (A), Buffer zones determined for Urban (B) and Urban map suitability **(C)**

Figure 12 depicts the urban map of the area researched, the buffer zones for urban and urban map appropriateness. Based on the notion that the consideration of urban sites would be good practice in ensuring good planning, landfills should be based at least 5000 m away from any major highways and city streets. That said, they should also not be too far away from existing road networks to prevent the excessive costs involved in constructing connected roads. The distance of a landfill site from an urban area is shown in **Table 1**.

The soil clay percentage and soil clay percentage suitability are illustrated in **Fig. 13**. The class of the soil land must be known as part of establishing whether the area is suitable for a landfill site. Moreover, a class such as clay would be assessed and given an appropriate index of land use suitability, and soil must have a clay percentage of greater than 25%. The percentage of soil clay for landfill sites is shown in **Table 2**.

The final map for the landfill site is shown in **Fig. 14**, and was generated based on **Fig. 4**. As illustrated, 6.3% of the chosen region appeared to be appropriate as a possible landfill site, whilst 93.7% of the area was unsuitable. **Figure 15** shows 18 possible sites within the researched area, ranging between 10 and 30 ha.

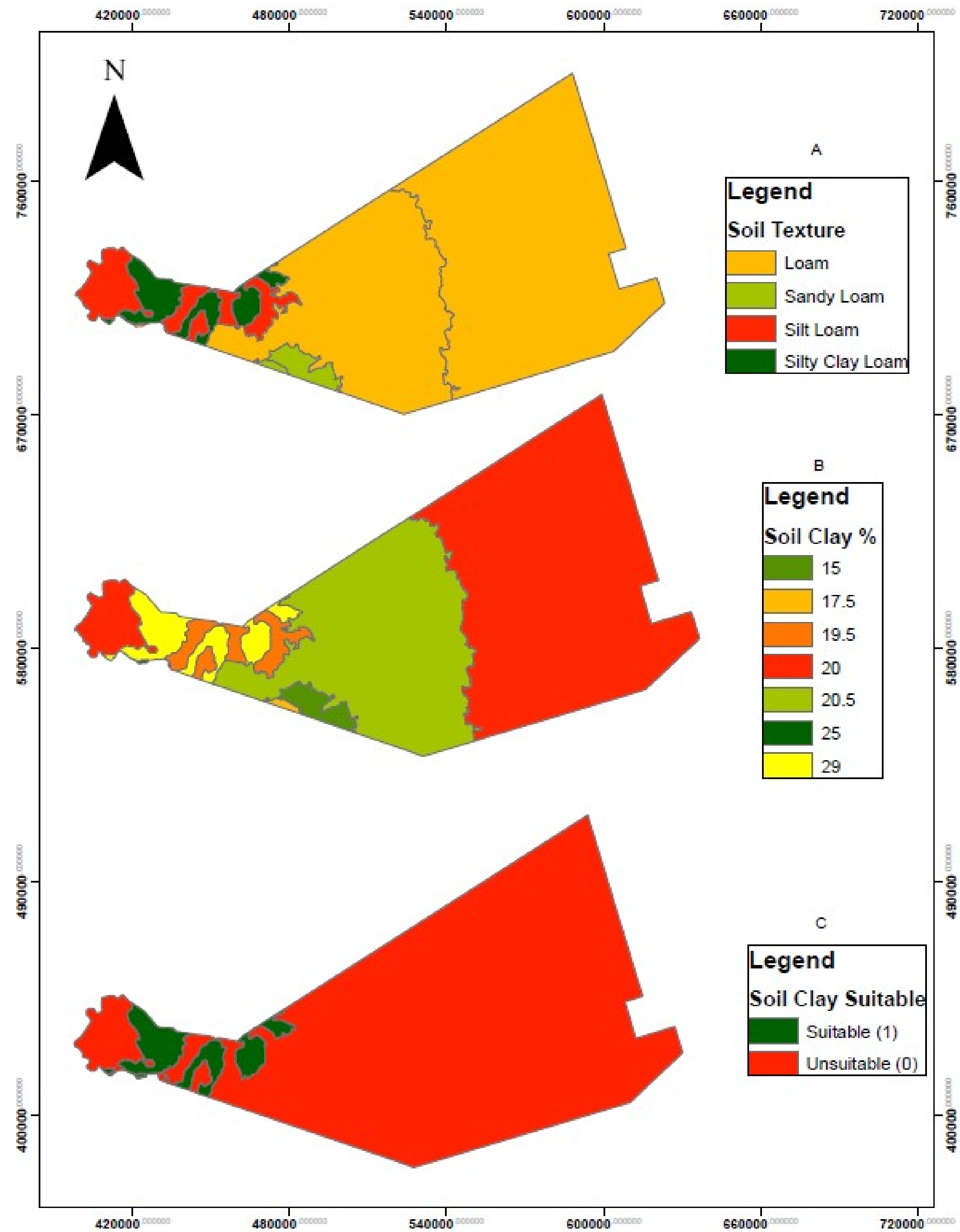

Fig. 13 Soil Texture (A), Soil Clay percentage of study area (B) and Soil Clay percentage suitability (C)

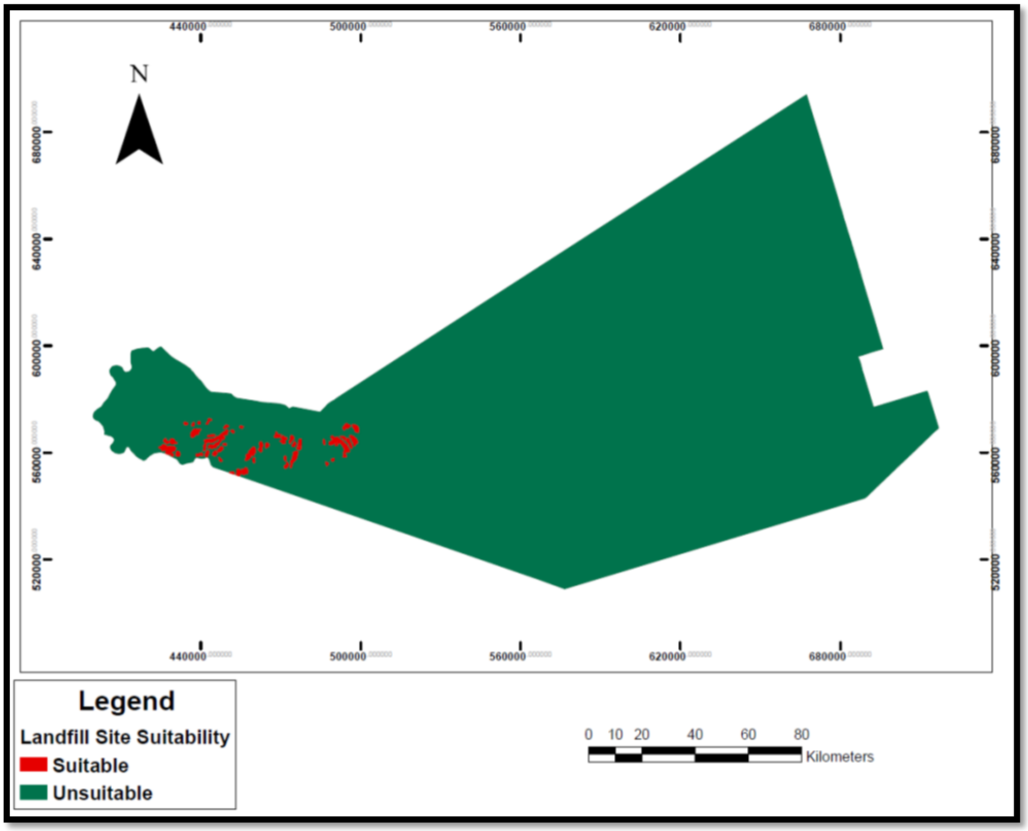

Fig. 14 Landfill site suitability in the study area

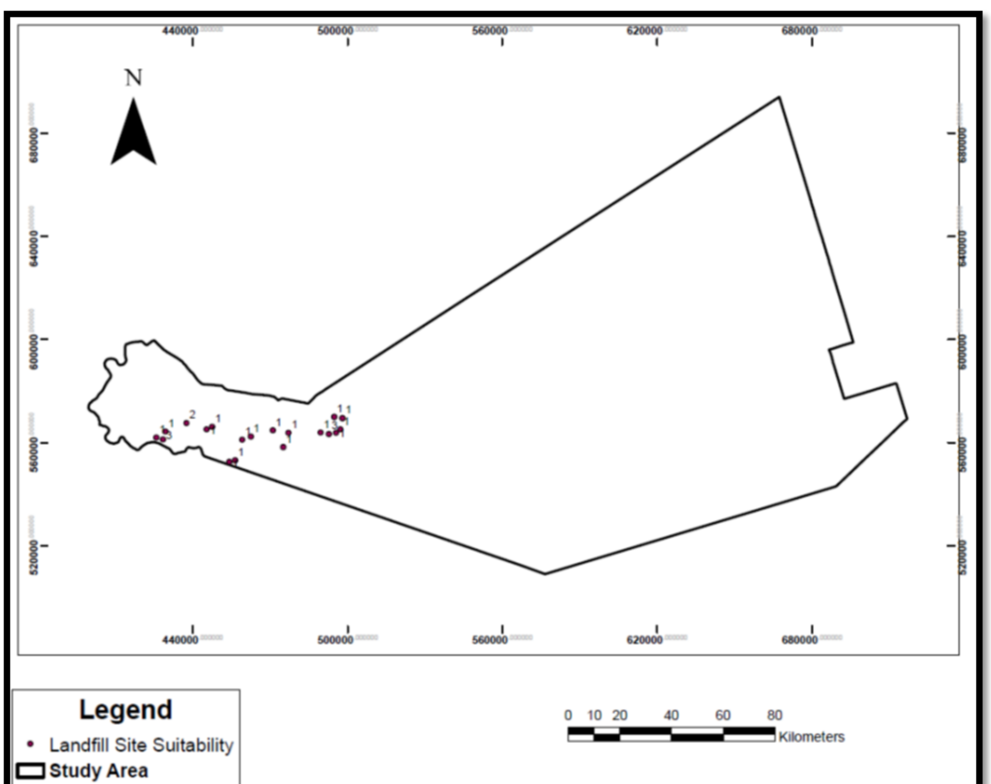

Fig. 15 The Eighteen candidate sites for landfill site in the study area

CONCLUSION AND RECOMMENDATIONS

The perfect instruments in determining the selection of suitable sites for landfill are the MCDA and GIS. Using vector analysis tools in GIS for assessing landfill sites saved time and expense, and produced a digital mass of information that can be accessed if a quick assessment of the chosen sites is needed in the future.

Vector analysis tools such as Buffer, Multiple Ring Buffer, Intersect, Union, Clip and Erase were used on several GIS layers to apply the Boolean techniques in choosing suitable landfill sites. The information was altered to work out the Boolean score based on the suitability and unsuitability of 9 criteria; Faults, Slope, Soil, Urban, airport, international Border, Wells, Wadis and Roads. The final map was divided into 2 classes, namely, suitable and non-suitable for a landfill site. Only sites with an area of 10 or greater were chosen and converted into layer points. The research demonstrated that only 18 sites within the research matched the criteria and were suitable as landfill sites.

The conclusions from the research will aid local government in choosing suitable sites for landfill in the future. In general, they do not have enough funds and experts to carry out a complete examination process that will stop extensive damage being caused to the environment.

The recommendations are that additional research is carried out by central and local governments to use the findings from this research to decide on the location of landfill sites.

To conclude, the choice of the final landfill site needs additional geotechnical, geophysical and hydrogeological assessment, to ensure that groundwater, as well as surface water, is protected.

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