Transportation Route Optimization of Municipal Solid Waste Using Network Analyst tool, Case of Jimma town, Southwestern Ethiopia

Beekan Gurmessa Gudeta (dhekoafuri@gmail.com)
Jimma University Institute of Technology
Fikadu Fufa Feyisa
Jimma University Institute of Technology
Wagari Mosisa Kitesa
Jimma University Institute of Technology

Research

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Abstract

Transportation of municipal solid waste to disposal sites takes a large percentage of its overall management costs. The objective of this study is to optimize the transportation route of municipal solid waste using the Network Analyst tool for Jimma town. The input data in the present study were coordinates of individual municipal solid waste collection container location and disposal site location, master plan, and road shapefile. Network Analyst, an extension of ArcGIS was the main software used in the study. The result obtained includes the proposed number and location of MSW container and the best possible route for the evacuation of municipal solid waste from individual container location to the disposal site. The minimum average distance to transport loaded containers from individual collection container locations to the disposal site and empty container to its location that optimized by the network analyst tool was 17.94 km. It is therefore recommended that the urban authority should do route planning for municipal solid waste collection vehicles within the urban area.

1. Introduction

1.1. Background of the study

In the world, an averagely about 4 billion tons of municipal solid wastes, MSW are discharged, and an amount of US$ 410 billion per year is spent from collection to recycling of solid waste [1]. The environmental values in rapid economic development, urbanization, and improving life level in cities leads to an increase in the quantity and complexity of generated waste, that representing a phenomenal challenge [2].

Municipal Solid Waste Management, MSWM is the proper management of various components such as generation from source, collection system, storage, transfer and transport, processing and treatment, and final disposal to landfill or dumping site [3]. Solid wastes contain heterogeneous contents of discharge from the urban community as well as the more accumulation of commercial, industrial, residential wastes, and other waste generators.

A mismanaged solid waste transportation has a negative impact on the environment and ecology heath in the community. These are a growing problem for national and local governments to ensure effective management of environmental sanitation and lack of controlled waste management [4]. 2003 WHO report indicated that the total health-care waste per person per year in most low-income countries is anywhere from 0.5 to 3 kg which is one of the cases for increases in health problems to citizens of low-income countries like Ethiopia.

Failure of the municipal solid waste management highly affects public health. It contaminates groundwater as well as surface water and increases air pollutants, leading to uncomfortable living conditions. Therefore an immediate demand to look into the issues of SWM and also improve the capability of town administration to manage SWM with the least cost as much as possible are necessary.

Because the solid waste transport cost alone comes to more than half of the total costs incurred in integrated solid waste management, ISWM in major cities of the world [1].

Now a days, integrated GIS technology with a prepared database provides an advanced modeling framework for decision-makers that analyze and simulate various problems related to solid waste management, SWM such as transportation route optimization. Inaddition GIS has been used to model various problems in waste management such as siting of landfills, optimizing the collection and transportation, and others [5].

1.1.1. Existing Municipal Solid Waste Disposal System in Jimma Town

The report of Jimma sanitary landfill environmental and social impact assessment 2013 indicated that the municipal solid waste, MSW of the town collected by the municipal truck openly dumped at southeastern part of the city near the Jimma airport on Bonga road. The dump site is located at about 4 km from the city center which is local name 'Qofe'. The municipal trucks dispose waste both to the right and left side Bonga road over a length of several hundreds of meters. During dry season the trucks go off road some hundreds of meters, whereas; during rainy season the trucks hardly go off roads; rather dump their load along the road left and right. It is also reported that some farmers request for wastes to be dumped on their farmland as fertilizer and soil enhancement.

1.1.2. ArcGIS Based Solid Waste Management

A geographical information system, GIS is a computerized system that permits to map, model, query, and analyze a large quantity of data within a single database according to their geographical location. It has the capability of making maps that integrate information visualize scenarios present powerful ideas, and develop effective solutions for various purposes. [3].

Solid waste management has used the ArcGIS tools model for the reduction of environmental and geographic related problems [4] by preparing an appropriate database. These reduced environmental problems are such as pollution, erosion problems, health problem, and others. Nikolaos [6], discussed that the model for the municipal solid waste generation and collection is a part of an extended solid waste management system and use a spatial geodatabase, integrated into a GIS environment. [7, 9 and 8] concluded that GIS can assist in analyzing coverage and reallocation of community bins by superimposing service or command area of bins over land-use imagery to find potential placing spots which could later be field checked for suitability and conformation to guidelines.

ArcGIS also used in simulating spatial data for facilitatating collection operations, analyzing optimal locations for transfer stations, and optimizing routes for vehicles transporting waste from residential [7, 10]. The application of this software currently helps in the simulation of reality for a particular phenomenon. A solid waste management, SWM is one of the problematic areas where the problems arise from day to day rapidly. The town municipalities were unable to provide a fully efficient system and even

are not able to reach an efficiency of more than half percent [1]. The geographical information system, GIS extension networkanalyst tool, NA toolbox contains tools that achieve the activities of network analysis and network dataset maintenance. It is a powerful extension of ArcGIS that provides network-based spatial analysis including routing, travel direction, closest facility, and service area analysis [12] and used for transportation route optimization in the present study.

1.2. statement of the problem

Urban transportations, particularly the phenomenon of congestion and pollution are the major problem of society [13]. The globalization of the economy leads to a rapidly growing exchange of goods, disposing of wastes, and other purposes by transportation on our planet. Collection and transportation of MSW was constituting more than 75% of the total SWM budget [14]. Therefore there is a high demand for cost reduction by using optimization techniques were the present study use a network analyst tool, NA to optimize solid waste, SW transportation route optimization.

In the town, there was an overflow of MSW due to improper transportation frequency to the disposal site (Fig. 1). This frequency of transportation affected by various factors and the main affecting factor is the existing transportation route was not properly designed. According to the information obtained from a government authority, Jimma town municipality has no design for the transportation route and frequency of transportation of the waste.

1.3. Objective of the study

1.3.1. General objective

The main objective the study was to optimize transportation route of municipal solid waste in Jimma town using ArcGIS network analyst tool

1.3.2. Specific objectives

- to propose new location of solid waste collection containers;
- to determine the shortest vehicle transportation route;

2. Material And Methods

2.1. Location of study area

This study was undertaken in Jimma town. Jimma is located in the Jimma zone of Oromiya National Regional State. Jimma is commercial center for coffee production region. It was located a longitude between 36° 46' 50" E to 36° 53' 20 " E and latitude between 7° 37' 1.164" N to 7° 46' 20.6904" N. An average elevation of 1780 meters above msl by the direction of south western Ethiopia about 354 km far from Addis Ababa, capital city of the countary along Addis- Mettu- Gambella road.

2.2. Data

2.2.1. The Spatial Data

The spatial data collected for the purpose of the present study are shown in the Table 1.

Table 1
Spatial data used in the study, their sources and purpose

Spatial data	Source	Purpose
Road Network	Jimma Town Municipality	For transportation route optimization and location allocation of MSW container
Existing MSW Container Location and disposal site location	Garmin GPS	For analysis existing location allocation of MSW containers and transportation route optimization
Jimma Town Master Plan	Jimma town municipality	To show detail location of master plan annotation when container location allocation was taken
Land Use Data	Jimma Town Municipality	Allocation of containers Collection and optimization

2.2.2. Containers Location Data

The location of MSW containers existing in the town was collected by using GPS. There was 16 places (total of 32 number of container) where MSW containers were allocated in the area of the town as the interview taken with town municipality authority indicates. In this study the whole 16 places of its latitude and longitude with in number and the size of each containers was collected.

2.2.3. Land Use Data

Land use data were obtained from the Jimma town master plan and classified on ArcGIS. The mainland uses of the town are administration zone, commercial zone, residential zone (existing house and housing expansion), manufacturing and storage (industrial zone), recreational and services such as public and religious institutions. The classified land use includes the future different land-use forecasted in the master plan.

2.2.4. Network Analyst Tool

The network analyst tool is the ArcGIS extension. In the present study, this NA was used for the optimization of transportation routes by using a spatial shapefile database. The best route optimized by using the algorithm of the NA tool. GIS extension network analyst provides a network-based spatial analysis including routing, travel directions, closest facility, and service area analysis [36]. In the present study, the route optimization function of the GIS NA tool was applied.

Having the collected data, the program NA is able to calculate which route is optimal from one point to another point when criteria of optimization are travel distance and time [15, 16]. The result that gained using the program were compared with the real figure of the road network and existed the destination point.

ArcGIS, NA can be used for finding the best route, finding the closest facility, calculating the service area, and creating a model. The database for these models can be created as a shape file-based network dataset, geodatabase network dataset, and multimodal network dataset [12]. Database for NA tool can be obtained from street map premium for ArcGIS, Vendor street data processing tools, open street map, OSM to NDS tools, and your own data [17, 18].

2.3. Data Preparation

The geospatial database was framed in ArcGIS for the allocation and analysis of MSW collection containers. The database was derived through sources such as digitalized maps, secondary spatial data, and online capturing with the use of GPS technology. Jimma town master plan in AutoCAD drawing that collected from the town municipality was imported/added to ArcGIS 10.4.1 and the road network was exported from the master plan in shapefile format. The shapefile format road network map use created for route optimization database with ArcGIS 10.4.1 Network Analyst tool in the Arc catalog.

The spatial location (latitude and longitude) of MSW containers and disposal sites collected by GPS was stored on Microsoft excel 2016 and saved by CSV (MS-DOS) format. The CSV (MS-DOS) data saved was added to ArcGIS 10.4.1 through add X-Y data and converted to shapefile format. The CAD annotation of the master plan AutoCAD drawing was exported through a conversion tool (to geodatabase-import CAD annotation) and saved alone that finally used in detail observing MSW site allocation in the newly proposed collection system.

The whole spatial data was projected for its geographical coordinate system, GCS and projected coordinate system, PCS. The geographical coordinate system used to define the projection was GCS-WGS 1984 and the projected coordinate system used to define the whole spatial data was Adindan UTM Zone 37. All work was accomplished and all software was run on Toshiba core i3 Window 10 pro computer.

2.4. Analysis for Transportation Route Optimization

The shapefile database was created in the Arc catalog for the NA tool that used for the optimization of the MSW transportation route. The database created was from the existing road that assesses a truck used for transportation MSW to the disposal site [17, 19]. For the case of Jimma town, due to the large size container (8 m3) exist and also to reduce the distance between each container location, the collection system was designed as HCS.

Using existing road access from each MSW collection container location to the landfill disposal site location the shortest route was determined by the NA tool from the shapefile database created in Arc

catalog ArcGIS 10.4.1. Using these tools the minimum distance was optimized from individual container location to landfill site [9, 14 and 20]

To do this first the MSW container location was overlaid on existing truck served road. Then from the ArcGIS desktop window, a new route was started in the network analyst tool and stops points were loaded. These stops were the location of individual collection container location and disposal site (landfill) location. Finally, the network analysis was performed to determine the best possible routes for vehicles during the evacuation of waste from the individual container location to the landfill disposal site

2.5. Model Used for the Optimal Allocation of Collection Container

In order to enhance (further improve) the current MSW collection services in the town, the present study investigated the inadequacy of existing collection container and their service areas. Thus to overcome this problem, initially the number of collection containers required was calculated on the basis of per capita MSW generation and population. The determination of number of collection container was given in Eq. (1) [19, 21]. To find the number of collection containers the total quantity of MSW generated was determined depending up on per individual person MSW generation and total population of the Jimma town and detail description was shown in appendix I. The population growth rate of Jimma town is 2.6% annually. The per capita MSW generation is about 0.55 kg/day (Getahun *et al* 2011; Jimma town municipality).

$N = W/ (D*S*F1*CF)$ (1)

Where N = Number of collection bins; W = Total quantity of waste generated per day in kg; D = Density of waste in kg/m^3; S = Size of collection container in m^3; F1 = Average filling rate of container, this value was most of the time 80 percent for 8 m^3 container [19] and CF = Collection Frequency

This proposed model helps to ensure efficient collection system of MSW in the Jimma town. Hence, it is necessary to define/identify the optimal locations of the MSW collection containers which helps to managing the difficulty occurred for the collection of MSW. The quick analysis in the decision making was performed by the ArcGIS. In this study GIS was used to locate the proposed containers location and their collection service area coverage for the entire area of the town with optimal proximity distance to the MSW containers. This provide a container location within a convenient distance range to all residents in the town administration area. To prove this newly forecasted model the proximity range of 0.5 km again checked by applying buffer around the new container site allocated.

3. Results And Discussions

3.1. Proposed Number and Location of Container

The number of MSW collection containers calculated for the 2018 year was 66 and after twenty years about 110 containers will be required. The total MSW generated from the residential area also calculated and the values are 88477.75 kg/day at the end of 2018 and 148,589.9 kg/day at 2038.

To improve the shortage an additional eleven proposed number of MSW collection containers sites were located optimally in the area of the town by the present study. These locations allocate was shown in Fig. 3 within the existing ones.

These area that allocated with new container allocation are Seto semero (two locations), Ifa Bula (one location), Qofe (one location), Bore (two locations), Ginjo (one location), Jiren (one location), Mandera Qoci (one location), Hirmata Merkato (one location) and Mentina (one location). By present additional location allocated each resident can use the MSW collection container by maximum walking distance of 0.5 km.

3.2. Optimal Allocation of Containers

The buffer result of individual container location was shown in the Fig. 4. It showed that 964 ha area was served by new location allocation of containers. The total area covered by buffered zone by buffering of CL by 0.5 km was about 2121 ha which 49.45% of boundary of town administration area. The areas that do not allocated with MSW container were areas with zero generation rate (such as forest, urban agriculture, recreational).

3.3. Municipal Solid Waste Transportation Route

The optimized transportation route of solid waste generated from residential areas of Jimma town was shown in Fig. 5. The minimum average distance to transport loaded containers from the MSW collection container location to the landfill disposal site and empty container to its location that optimized by the network analyst tool was about 17.94 km.

The total distance covered by the transportation of 66 loaded and empty MSW containers collected for three days was about 1184 km (17.94 km * 66, where 66 is the number of containers). This optimized route was the shortest possible distance that the truck can travel from the collection site to the landfill location.

The finding was used to properly manage MSW. And also used to minimize transportation cost and environmental pollution by reducing the emission of Carbon dioxide as the transportation distance become minimum. Minimization of cost means not only minimization of travel distance but also the total time (collection time and travel time) [22].

Therefore the municipality has to train the driver of truck loading solid waste to a disposal site, in the order, they use the shortest possible distance or optimized transportation route. Using this optimized

route municipality can facilitate the transportation system of Jimma town household generated solid waste.

4. Conclusions

To reduce the problems that come due to solid waste improper management system GIS and remote sensing can be effectively used in the management of solid waste and collection container location-allocation and transportation route optimization. The present study was used to minimize currently existing problems in the municipal solid waste management system of the Jimma town specifically in the MSW transportation route and container location-allocation.

Using the application of ArcGIS software in municipal solid waste management in urban areas like Jimma town municipality can improve waste collection system efficiency by properly allocating containers (collection bins). Applying this software also used to minimize the operational cost of the transportation systems in solid waste disposal as the best transportation route optimized by using a network analyst tool.

For the unserved area, about 11 new CL was proposed and the proximity distance was checked. The total 27 CL (16 existing and 11 proposed) was cover about 21 and 49.45% of the boundary of the town master plan and administration area respectively. The shortest route was optimized from an individual container location to the Landfill disposal site. The total distance covered by the transportation of 66 loaded and empty MSW containers collected for three days was about 1184 km (17.94 km * 66, where 66 is the number of containers). This optimized route was the shortest possible distance that the truck can travel from the collection site to the landfill location.

Declarations

Authors contribution

B.G. (MSc, lecturer) conducted all the experiments and wrote the manuscript, F. F. (PHD, associate professor) wrote and revised the muniscript, W.M. (MSc, lecturer) revise the manuscript.

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References

1. Sanjeevi V, Shahabudeen P. Network Optimization of Solid Wastes Management in Chennai, India: case study, Journal of Environmental Science, Toxicology and Food Technology, 2016, 10 (8): 2319–2399.
2. Nigatu R., Rajan D., Bizunesh **B**. Challenges and Opportunities in Municipal Solid Waste Management: The Case of Addis Ababa City, Central Ethiopia, J Hum Ecol, 2011, 33(3): 179–190.
3. **Shamshad A**., **Kafeel A**. Modeling of Municipal Solid Waste Management System Using Powersim Studio–A Case Study, Journal of Energy Research and Environmental Technology, 2015, 2 (2): 117–122.
4. **Assa B.** An Investigation on Rout Network Analysis by Raster Method in the Context Sustainable Solid Waste Management A Case of Wolyta Soddo, Journal of Environment and Earth Science. 2015, 5 (15): 2224–3216.
5. Amjad Kallel, **Mohamed Moncef Serbaji**, **Moncef Zairi**. Using GIS-Based Tools for the Optimization of Solid Waste Collection and Transport: Case Study of Sfax City, Tunisia, Journal of Engineering, vol. 2016, Article ID 4596849, 7 pages, 2016. **https://doi.org/10.1155/2016/4596849**
6. **Nikolaos V**., **Vassili G**. GIS-based modelling for the estimation of municipal solid waste generation and collection, Waste Management and Research, 26(2008): 337–346.
7. Mohammedshum A., Gebresilassie M., Rulinda M., Kahsay H., Tesfay **S**. Application of geographic information system and remote sensing in effective solid waste disposal sites selection in Wukro town, Tigray, Ethiopia, The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 2014, 11(2): 115–119.
8. Joel R., Charles B., Girma G., Allan **J**., **Bjorn V**. Mapping out the solid waste generation and collection models: the case of kambala city, journal of the air and waste management association 65(2015): 197–205.
9. **Ashtashil V**. Municipal solid waste collection routes optimized with ArcGIS network analyst tool, international journal of advanced engineering science and technologies, 2017, 11(1): 202–207.
10. Danbuzu L., Tanko I., Ibrahim A., Ahmed **M**. Spatial Distribution of Solid Waste Collection Points Using GIS Approach In Urban Katsina, Katsina State, Nigeria, American Journal of Engineering Research (AJER), 2014, 3 (7): 107–116
11. Bhambulkar, Isha.P. Khedikar. GIS based service area analysis for optimal planning strategies: a case study of fire service station in madurai city, journal of engineering and technology, 2014, 5(2): 12–18.
12. **ESRI**. What is new in ArcGIS? Printed in the United States of America, 380 New York Street, Redlands. 2006, Third edition.
13. **Patricia J., Carlosa G., Guillermo G.** Route optimization of urban public transportation optimization, journal of science and technology, 2013, 80(180): 41–50.
14. **CHALKIAS C**., **LASARIDI K**.. A GIS model for optimization of municipal solid waste collection: the case study of Nikea, Athens, Greece, WSEAS Transactions on environment and development, 2009, 5(10): 1790–5079.

15. Nagla A., Mohammed S. Route network analysis in Khartoum city, Journal of engineering and computer science, 2016, 17(1): 50–58.
16. Lucie V., Vit **V**. Analysis of traffic capacity using ArcGIS network analyst tool, Olomouc Czech Republic, 2014, 11(4): 129–143.
17. Johnbosco C. Ojiako, Ebele J. Emengini, Jude N. Iwuchukwu. Geographic Information System (GIS) Approach to Solid Waste Management in Onitsha Urban Anambra State, Nigeria International journal of scientific and engineering research, 2014, 5 (12): 2229–2235.
18. Deelesh M., Dmitry **K**. Network Analysis with ArcGIS for Server, San Diego, California, ESRI international user conference, 2012 (https://maps.uky.edu/esriuc/esri_uc2k12/Files/92.pdf) accessed on august, 2018.
19. Nithya R, Velumani A., Senthil R. Optimal Location and Proximity Distance of Municipal Solid Waste Collection Bin Using GIS: a Case Study of Coimbatore City, WSEAS transactions on environment and development, 2012, 4(8): 107–118.
20. Samidha S., Isha K., Anil **C**. Route Optimisation for Solid Waste Management Using Geo- Informatics, Journal of Mechanical and Civil Engineering (IOSRJMCE), 2012, 2(1): 78–83.
21. **Ali I**., **Umar M**. An appraisal of distribution of solid waste disposal sitesin Kano Metropolis, Nigeria, 2017(5): 24–36.
22. **Khanh N**., **Anh N**., **Doanh N**., **Van D**. Optimization of municipal solid waste transportation by integrating GIS analysis, equation-based, and agent-based model, Waste Management 59 (2017): 14–22.

Figures

Figure 1

Solid waste collection container location

Figure 1

Solid waste collection container location

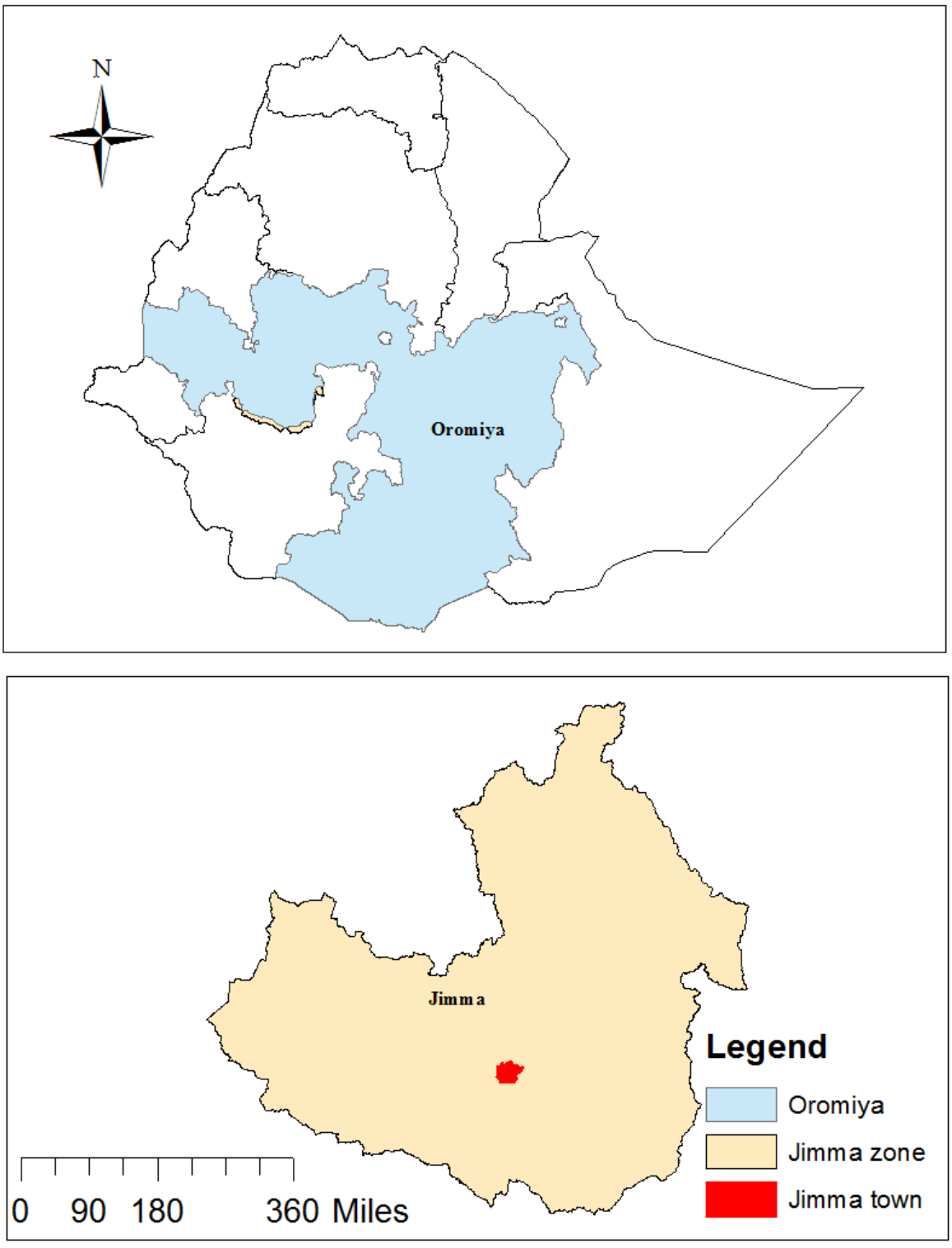

Figure 2

Map of the study are Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the

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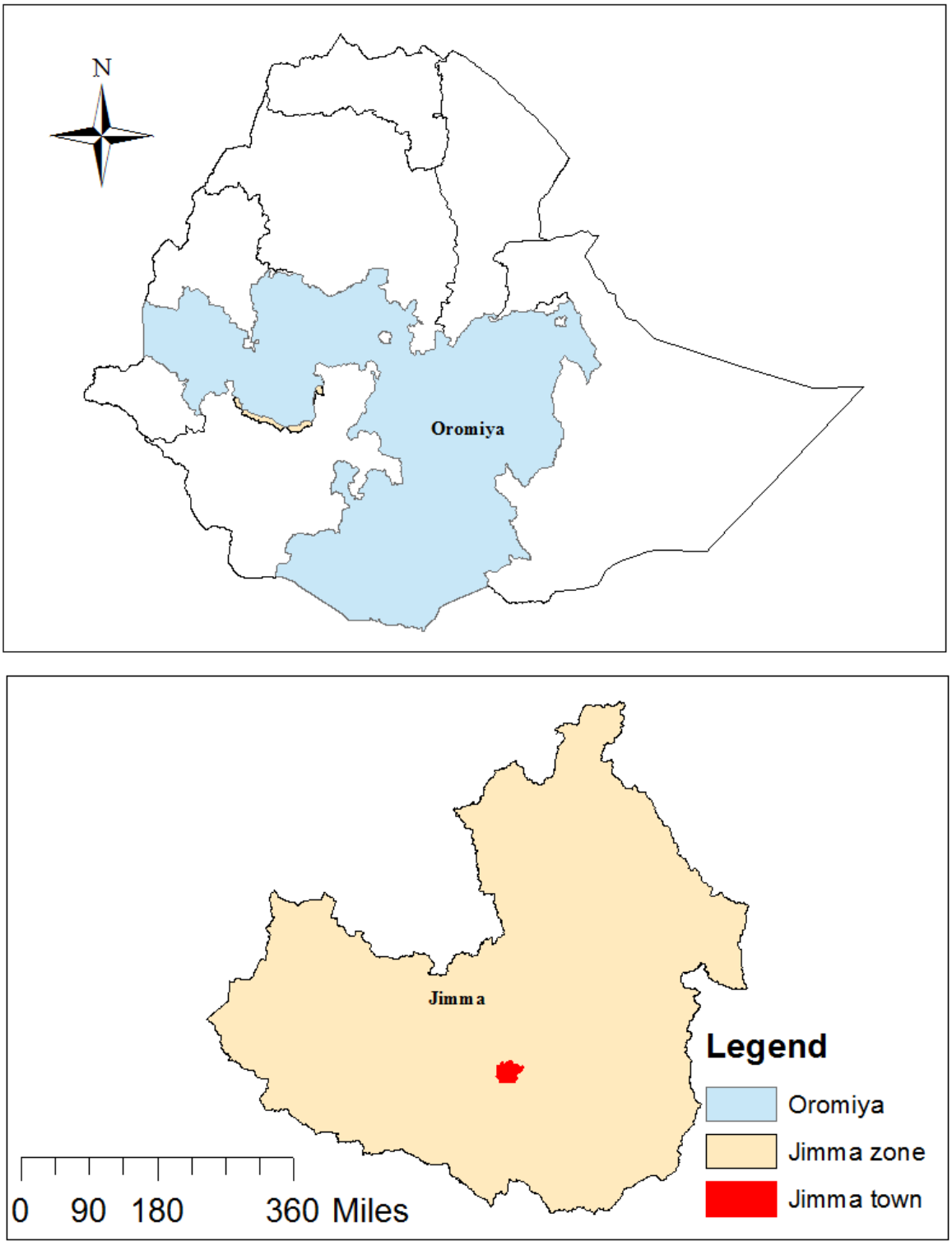

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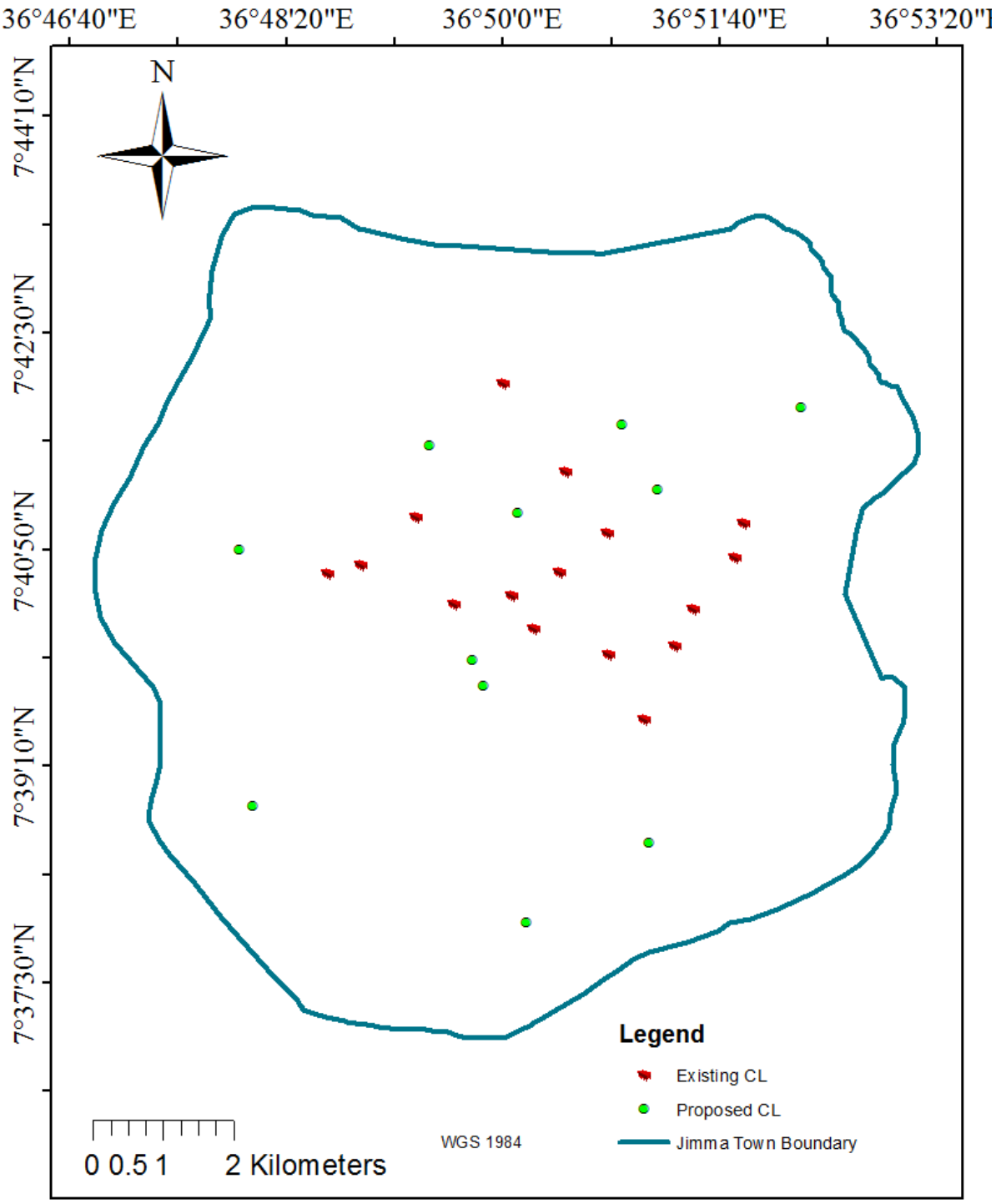

Figure 3

Proposed and existing container location Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research

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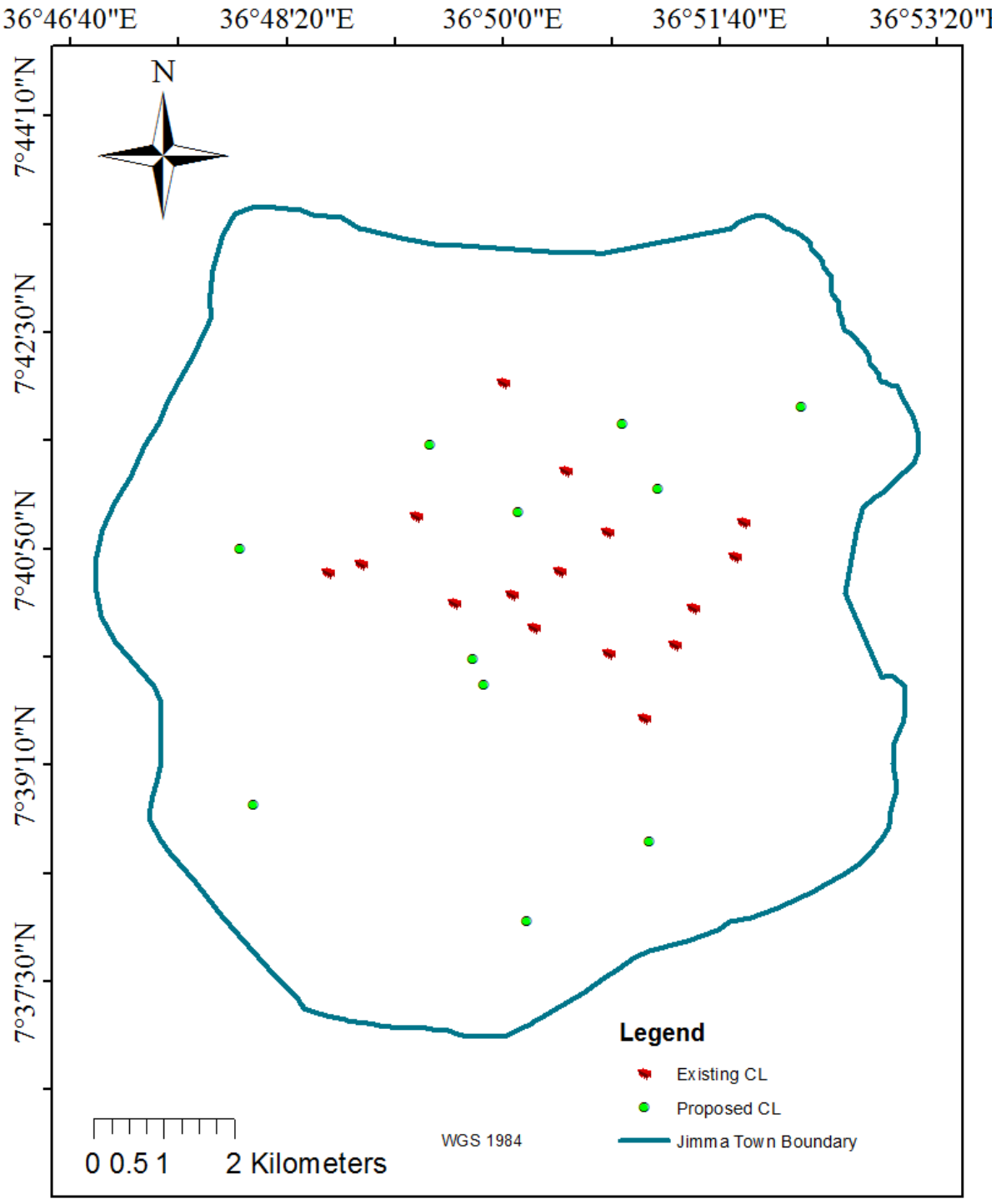

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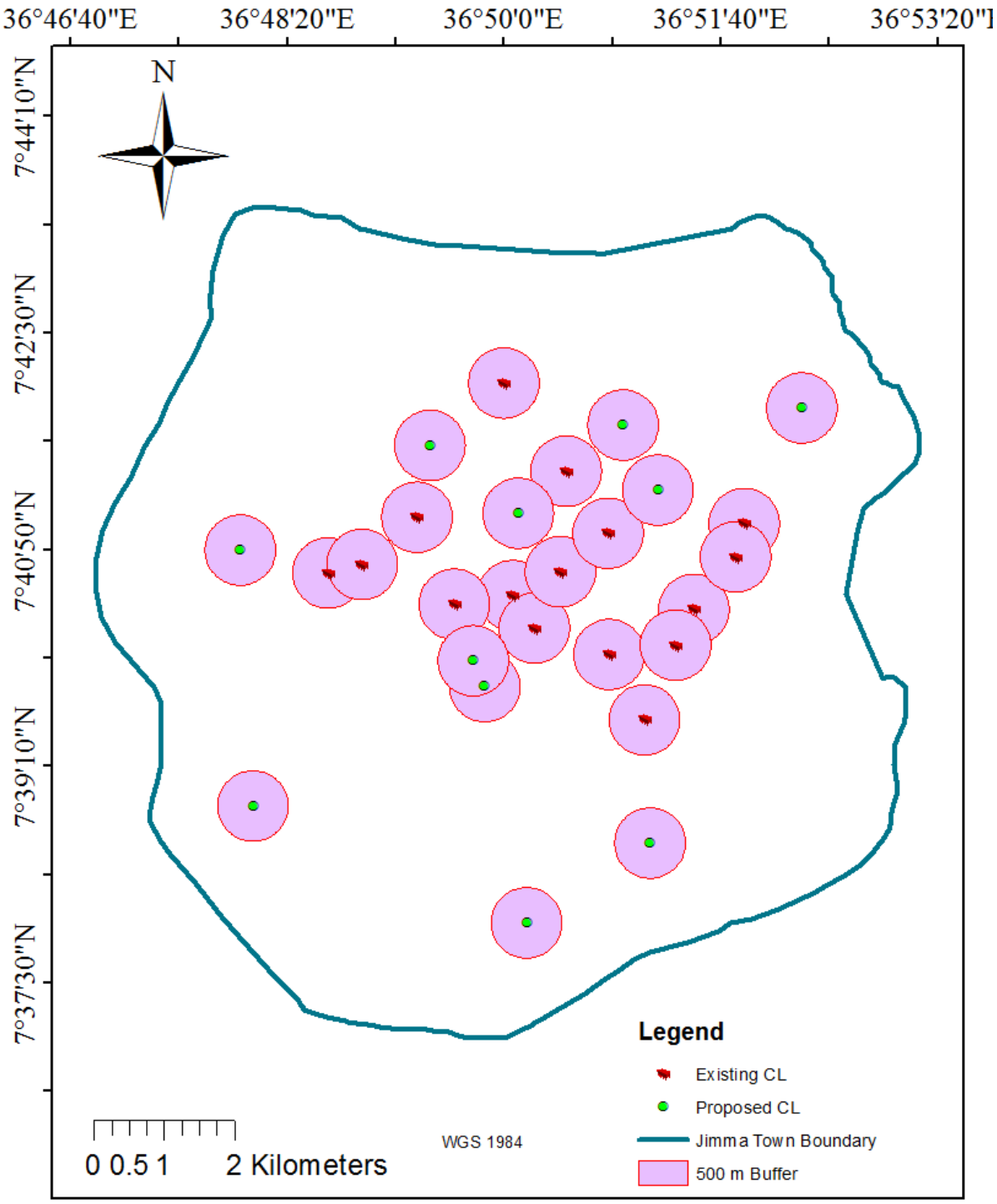

Figure 4

0.5 km radius buffered area of proposed and existing container location Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or

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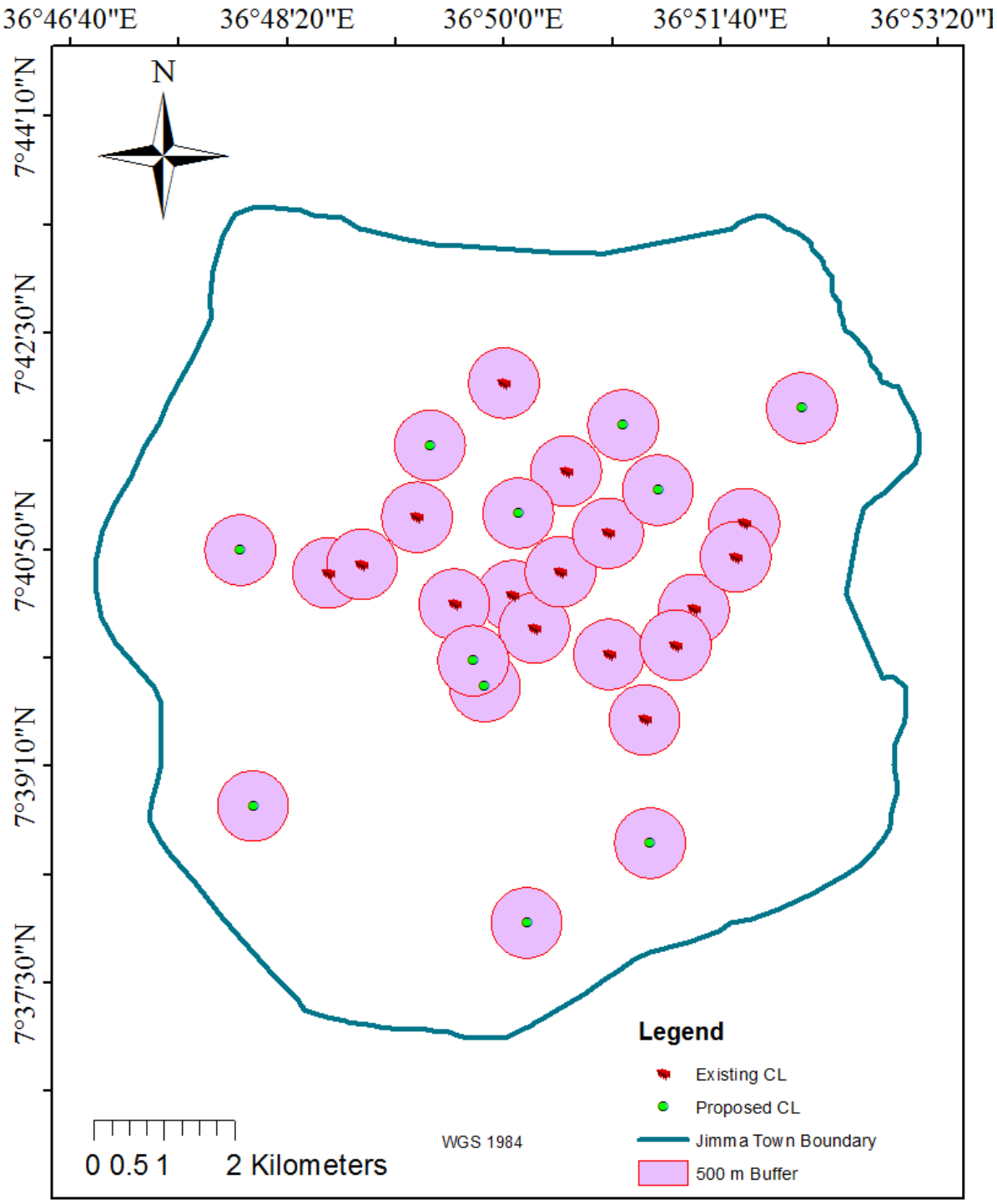

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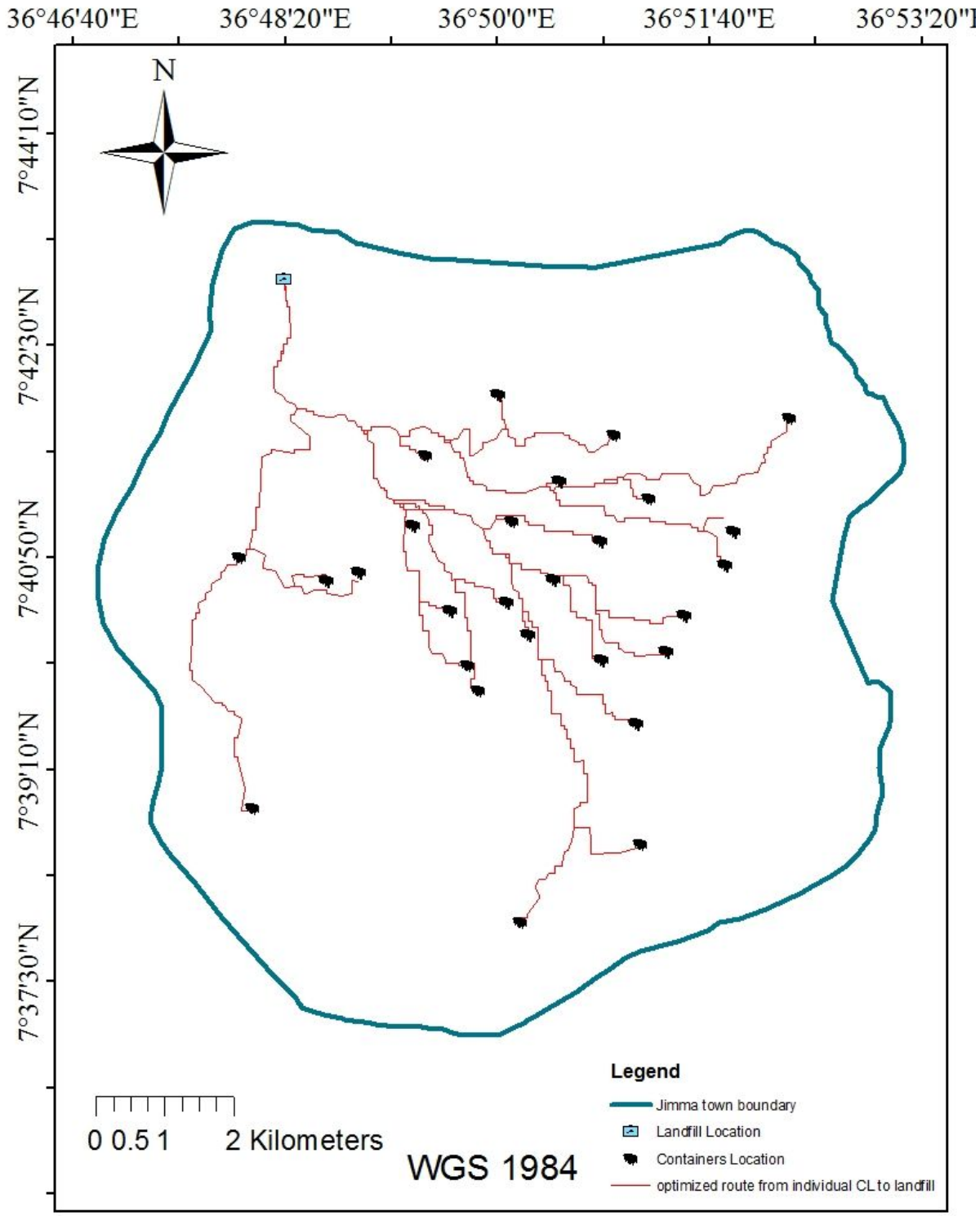

Figure 5

Optimized MSW transportation route of the town Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of

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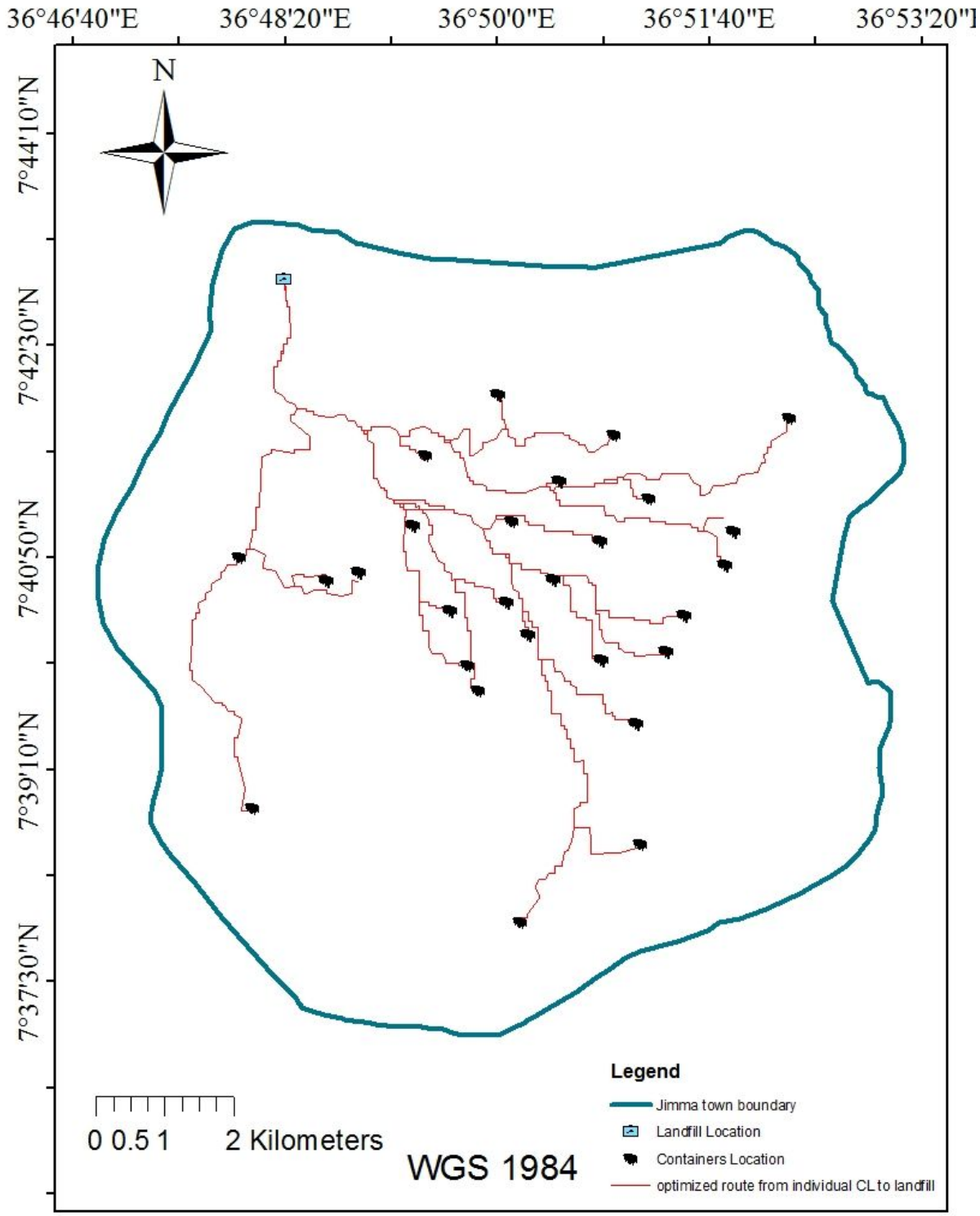

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