Monitoring of UN Sustainable Development Goal SDG-9.1.1: A case study of Algerian “Belt and Road” expressways constructed by China (#41474)

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Monitoring of UN Sustainable Development Goal SDG-9.1.1: A case study of Algerian “Belt and Road” expressways constructed by China

Zhanhai Jia [1], **Mingquan Wu** [Corresp., 2], **Zheng Niu** [2], **Bin Tang** [1], **Yuxuan Mu** [3]

[1] College of Earth Sciences, Chengdu University of Technology, Chengdu, Si chuan Province, China

[2] The State Key Laboratory of Remote Sensing Science, Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences, Beijing, China

[3] College of Tourism and Urban-Rural Planning, Chengdu University of Technology, Chengdu, Si chuan Province, China

Corresponding Author: Mingquan Wu
Email address: wumq@radi.ac.cn

The proportion of the rural population living within 2 km of roads ~~that pass through the year-round~~ is a sub-goal of the United Nations’ Sustainable Development Goals (SDGs) 9.1.1. At present, there are few research methods for monitoring this indicator at home and abroad. ~~In response to this problem,~~ three SDG Goal 9.1.1 monitoring methods are proposed for different spatial regions based on the five highways built by China in Algeria. These methods are based on remote sensing and WorldPop and The High Resolution Settlement Layer(HRSL) population data. The WorldPop population statistics show that the five highways built by ~~China~~ have increased the rural population of the 2 km buffer zone by 196,000 between the start of construction and eight years after its completion. By the end of 2019, the population increased by 252,687, accounting for 9.16% of the rural population. ~~(2)~~ Based on populations estimated form built-up index (NDBI) building areas, the rural populations ~~in~~ the 2 km buffer area of the Bekaya-Haniff Expressway in 2011, 2015, and 2019 were 273,118, 306,430, and 375,408, respectively. (3) HRSL population grid statistics indicate that the East-West Expressway, Bejaia Expressway, Tibza Expressway, North-South Expressway, and Tipaza Expressway had populations of 911,549, 127,471, 71,411, 30,583, and 41,657, respectively, in 2015. ~~Remote sensing monitoring visual interpretation~~ indicates that, ~~according to~~ the number of buildings and their numbers of floors, the rural population in Tikhramtath town in 2011, 2015, 2017, and 2019 was 1790, 2785, 3365, and 3970, respectively. (5) Through analysis and accuracy assessment, the appropriate statistical methods for different regions were determined.

Monitoring of UN Sustainable Development Goal SDG-9.1.1: A Case Study of Algerian "Belt and Road" Expressways Constructed by China

Zhanhai Jia[1],Mingquan Wu[2], Zheng Niu[2], Bin Tang[1],Yuxuan Mu[3]

[1] College of Earth Sciences, Chengdu University of Technology, Chengdu, China;

[2] The State Key Laboratory of Remote Sensing Science, Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences, Beijing, China;

[3] College of Tourism and Urban-Rural Planning, Chengdu University of Technology, Chengdu, China;

Corresponding Author:

Mingquan Wu[2]

P.O.Box 9718, Datun Road , Chaoyang, Beijing, 100101, China;

Email address: wumq@radi.ac.cn;Tel.:+86-10-6480-6258

Abstract

The proportion of the rural population living within 2 km of roads that pass through the year-round is a sub-goal of the United Nations' Sustainable Development Goals (SDGs) 9.1.1. At present, there are few research methods for monitoring this indicator at home and abroad. In response to this problem, three SDG Goal 9.1.1 monitoring methods are proposed for different spatial regions based on the five highways built by China in Algeria. These methods are based on remote sensing and WorldPop and The High Resolution Settlement Layer(HRSL) population data. The WorldPop population statistics show that the five highways built by China have increased the rural population of the 2 km buffer zone by 196,000 between the start of construction and eight years after its completion. By the end of 2019, the population increased by 252,687, accounting for 9.16% of the rural population. (2) Based on populations estimated form built-up index (NDBI) building areas, the rural populations in the 2 km buffer area of the Bekaya-Haniff Expressway in 2011, 2015, and 2019 were 273,118, 306,430, and 375,408, respectively. (3) HRSL population grid statistics indicate that the East-West Expressway, Bejaia Expressway, Tibza Expressway, North-South Expressway, and Tipaza Expressway had populations of 911,549, 127,471, 71,411, 30,583, and 41,657, respectively, in 2015. Remote sensing monitoring visual interpretation indicates that, according to the number of buildings and their numbers of floors, the rural population in Tikhramtath town in 2011, 2015, 2017, and 2019 was 1790, 2785, 3365, and 3970, respectively. (5) Through analysis and accuracy assessment, the appropriate statistical methods for different regions were determined.

Introduction

The UN's Sustainable Development Goals were proposed in 2015 and include ~~17~~ categories of social, economic and environmental problems ~~that are projected to take 15 years to solve completely. Sub-goal of the 9th category of targets~~ SDG9 (Industry, Innovation and Infrastructure) 9.1.1 is the proportion of the rural population living two kilometers on the roads ~~that pass through the year-round.~~ China's Belt and Road Initiative has undertaken a large number of highway projects, which have promoted the development of local economies and helped to achieve the UN 2030 target SDG9.1.1 (~~Hutton & Varughese., 2016; Scipioni et al., 2009; Xue &Weng., 2017; Pfaff et al., 2018;~~ Mikou et al., 2019).

~~The spatial distribution of a population reflects the natural conditions and economic development of an area to a certain extent (Yang, Yue & Gao., 2013). Therefore, counting the number of people within 2 km of a road is crucial.~~ Population statistics ~~obtained by censuses by administrative districts~~ have problems such as low temporal and spatial resolution and infrequent updating. (Gao et al., 2013). There is a method of converting population counts from past census units into grids comprising units that are basically administrative locations with irregular shapes and resolutions (Tobler.,1979). ~~It uses GIS technology to weight nighttime remote sensing images and basic statistical information and uses GIS spatial analysis to perform overlay analysis to distribute census data to multiple pixels (Wu, Xu & Wu., 2015).~~ The Transportation Title Indicator, the rural access index (RAI), was approved by the World Bank's Transport Sector Council in 2003 . RAI measures the proportion of the rural population that resides within two kilometers of a road that can be used year-round. The WorldPop project was launched in October 2013. WorldPop demographic data has a spatial resolution of 100 m. When new data is available, WorldPop is updated, providing current, past and projected population estimates (Roberts, Kc & Rastogi., 2006). However, it is not possible to count the population of a building in a small area. China's Belt and Road infrastructure interconnection process is relatively fast and has effectively promoted local social and economic development. However, methods of calculating the proportion of the rural population that resides within 2 km of a road has received little study, both in China and elsewhere.

In response to this problem, based on remote sensing and The High Resolution Settlement Layer (HRSL) population data, this paper takes five Algerian highways built by China as an example. Three SDG9.1.1 assessment methods are proposed. The specific method objectives include: 1) Based on a large regional scope, an evaluation method based on HRSL population data is proposed to evaluate and analyze the contribution of five Algerian highways built by China to the ~~SDG 9.1.1 target~~ in 2015. 2) Based on a medium-area scope, the NDBI building area population estimation method is used to evaluate and analyze the rural population that resided within 2 km of a road in 2011, 2015 and 2019 of the Bekaya-Hanif Expressway in Algeria. 3) Using the SDG9.1.1 assessment method based on remote sensing monitoring, the population of

Tikhramtath town, which is within two kilometers of the Bekaya-Hanif road in Algeria, was assessed and analyzed.

Research area and data

Research area

China has built five expressways in Algeria (Table 1). The total length of the East-West Expressway in Algeria is 1216 km, of which 528 km of the middle and western sections are under construction by China International Trust Co., Ltd. and China Railway Construction Co., Ltd. The project has adopted the engineering procurement construction contracting mode and European technical standards. The construction of the expressway has promoted the growth of Eastern and Western economies in Algeria, reduced the rate of traffic accidents, and formed a new space for social development. The Tipaza 48 km Expressway was built in the middle of five bureaus. The north-south expressway is 3,000 km long, and the China Construction Company undertook the 53 km Chiffa to Berrouaghia section. It is the most difficult and complicated section of the North-South Expressway, containing nearly 100 bridges and 76 viaducts. The full length of the city is 17 km, and it was built by the China Construction Company. The construction of the road greatly eased pressure on the N11 route and served as an extension of the 48 km expressway. The ~~Bejaia~~ connecting expressway project starts from the port of Bejaia in the north and connects to the East-West Expressway in the south. The project ~~will better~~ service the port of Bejaia, while at the same time improving the local economy. The development has also eased traffic congestion in the area (Fig. 1).

~~Data source~~

This paper uses WorldPop ~~and~~ HRSL population raster data, Landsat remote sensing imagery, ~~and an~~ Algerian urban area and administrative division map. The WorldPop project was launched in 2013. It uses raster prediction based on a random forest model to generate a 100 m spatial resolution population density, which is then used as a weighted surface and redistributed according to national population data (Stevens et al., 2015). WorldPop data has lower resolution and is constantly updated with better data. Unlike landscan data, WorldPop data is free and publically-available (Stevens et al., 2015). HRSL population data has a resolution of 30 m and was obtained from the Center for International Earth Science Information Network (CIESIN). GADM is a public database of global administrative divisions and has a higher spatial resolution than other free databases. Landsat 5 and Landsat 8 data were obtained from the US Geological Survey (Table 2).

Research methods

Taking five highways built in Algeria by China as an example, this paper proposes three sustainable development goals SDG-9.1.1 monitoring and evaluation methods, from large to small areas (Fig. 2). 1) Obtaining large-scale statistics based on HRSL population data, using the GIS nearest neighbor method and regional statistical method to evaluate and analyze the contribution of five Algerian highways built by China to SDG-9.1.1 in the past five years; 2) For medium-sized areas, an evaluation method based on the NDBI building area index (SDG-9.1.1) is proposed. 3) For small areas, an evaluation method based on high-resolution time series images is proposed. 4) Analysis and comparison of the WorldPop population statistics method.

(1) A large-scale SDG-9.1.1 evaluation method based on HRSL population raster data

In this paper, the population statistics of residents within two kilometers of five highways are studied using HRSL population data and GIS nearest neighbor and regional statistics methods. The nearest neighbor method locates the positions of pixels in the output image to the original image by the nearest neighbor method. It finds the nearest pixel from the original image and takes the value of the pixel as the value of the output image pixel. The nearest neighbor method is used to calculate the size of a single grid pixel. Then, by using the ARCGIS function of regional statistical analysis, all the grid pixel values are tabulated and, finally, the sum of all pixel values is calculated (Caraway, McCreight & Rajagopalan., 2014; Rossi, Dungan & Beck., 1994).

(2)Evaluation method of a medium area SDG-9.1.1 based on the NDBI building area index

The Middle Area comprises the Bekaya-Haniff Link Expressway in Algeria and uses the NDBI building area population estimation method for demographic analysis. A two-kilometer NDBI distribution map of the Bekaya-Haniff Link Expressway road was calculated using Landsat remote sensing images from 2011, 2015, and 2019 and is presented in Fig. 3.

The normalized difference building index (NDBI) indicates the distribution of land for regional construction (Li & Chen., 2018; Li et al., 2017; Xu., 2008). The calculation method is shown in Equation 1.

$$NDBI = \frac{MIR - NIR}{MIR + NIR} \quad (1)$$

Where: NDBI represents the normalized building index, MIR represents mid-infrared reflectance, and NIR represents near-infrared reflectance.

Supervised classification: The maximum likelihood method is used to extract a sample from the whole population to ensure that the same block with the same band value as the sample is assigned the same attributes belonging to the same type of feature (Cabral et al., 2018; Murthy, Raju & Badrinath., 2003; Otukei & Blaschke., 2010; Keuchel et al.,2003). Combining remote sensing images of the study area with data on its land types, we categorized the land types as residential, forest, cultivated, and bare by visual interpretation. Then, 100 uniformly distributed samples were selected from the entire image (Table 3). After many experiments, the separability between each sample type was greater than 1.8 and the maximum likelihood algorithm was selected for classification. Finally, combined with 0.3m high-resolution remote sensing image for accuracy verification, the accuracy of the verification results is above 90% (Li et al., 2014; Zhang et al., 2016; Pujiono et al., 2019).

NDBI was calculated using the Landsat-5 and Landsat-8 remote sensing image bands to extract the area of rural buildings, and the area of rural buildings within two kilometers of the highway in 2011, 2015 and 2019 was estimated. In order to maintain the accuracy of extracting buildings and eliminate the effects of bare soil, cultivated land and water bodies, the bare soil and cultivated land were extracted by the supervised classification maximum likelihood method, while water bodies were extracted by visual interpretation. Finally, the NDBI was masked by areas of bare soil, cultivated land and water bodies to obtain a map of the rural building distribution. The total population is then calculated based on the total area of the building and the per capita living area.

(3)Small-scale S~~DG-9.1.1~~ evaluation method based on high-resolution time series images

The small area of the town of Tikhramtath in the Bekaya-Haniff buffer zone of Algeria was analyzed in terms of demographics. A remote sensing method was used to monitor changes in buildings in 2011, 2015, 2017 and 2019 in small areas according to a multi-time remote sensing data map. A visual interpretation of the number of buildings and number of floors in the domains was carried out through 0.24 m high-resolution remote sensing images. Then, according to the size of the building, the population of each floor of each building was estimated to calculate the total population of the area.

(4)Accuracy evaluation and comparative analysis

Comparisons of the populations and the results of the three methods presented in the article were made. The root mean square error (RMSE) and relative RMSE (%RMSE) were used to measure the accuracy of Global Human Settlement (GHS) data with WorldPop data, HRSL data, NDBI estimated building area data, and remote sensing visual interpretation data. The %RMSE values were obtained by dividing the RMSEs by the average of the number of censuses, which can

reflect the accuracy of the model simulation. Finally, the most suitable population calculation methods for different regions were selected(Tan et al., 2017; Draperet al., 2013; Bhunia, Shit & Maiti., 2018).

$$RMSE = \sqrt{\frac{1}{N}\sum(f_i - r_i)^2} \quad (2)$$

$$\%RMSE = \frac{RMSE}{\frac{1}{N}\sum r_i} \quad (3)$$

Where fi is the estimated value of the ith group of data, that is, the estimated population density obtained after population spatialization; ri is the reference value of the ith data, that is, the population density value obtained from the census data; N represents group data.

Experimental results

Based on WorldPop population statistics

Algerian urban demographic results

The statistics of the Algerian urban population are crucial to the statistics of the rural population. The rural population size is based on the total population minus the urban population. The distribution of the Algerian urban population from 2009 to 2019 is shown in Fig. 4. The sizes of the urban population in 2009, 2011, 2013, 2015, 2017 and 2019 were 11,396,261, 11,857,311, 12,632,705, 13,302,082, 14,019,482, and 14,820,436, respectively. In these years, the total rural population was 23,247,534, 24,126,163, 24,821,053, 25,788,594, 26,896,482, and 28,158,778 people.

According to the comparison of urban population changes, Fig. 4 shows that there are 84 cities in Algeria, five of which with an area of 200 km² or more, all of which are located in the northern part of Algeria. The population of urban areas has grown rapidly over the last 10 years, with a total growth of 3,424,085 people. The urban areas along the new highways are particularly obvious, including Oran, Algiers, Blida, Bouira, Sidi-Bel-Abbes and other larger cities.

Demographic results of the provinces of Algeria

Population data from the provinces of Algeria play an important role in calculating the proportion of the rural population that lives within 2 km of an expressway. Fig. 5 shows that the top three most populous provinces in Algeria are Algiers, Setif, and Oran, with populations of 3,037,455, 1,510,132 and 1,483,869, respectively. The three provinces with the smallest populations are Tindouf, Illizi, and Tamanghasset, with populations of 52,170, 54,636 and 181,217, respectively. The population growth rate of each province is low. In 2009-2011, the growth rate was above 10%, being 12.678% in Tindouf Province. In 2011-2013, the growth rate was above 10%.

The provinces with growth rates > 10% during 2015-2017 were Naama Province, Tindouf Province, and Tiaret Province, with growth rates of 11.132%, 12.678% and 17.411%, respectively. Tiziwuzu Province had the lowest growth rate at 0.516%. The provinces with growth rates > 10% in 2017-2019 were the same, with growth rates of 11.694%, 12.678% and 22.306%, respectively, while Tiziwuzu Province had the lowest growth rate at 0.545% (Fig. 6).

China's construction of five highways in Algeria: SDG-9.1.1 assessment

The Worldpop population raster data was counted as follows. (1) A expressway 2-km buffer surface was created using ARCGIS tool “Feature to polygon” (2) Natural Earth urban area data was based on the ArcGIS tool “Extract by mask” to obtain the urban population raster data, then the spatial analysis tool “Raster calculator” was used to obtain the rural population raster map. (3) The generated buffer surface was obtained using the “Extract by mask” tool to obtain 2-km rural population raster data. (4) The Worldpop cell raster layer was converted to a vector point layer through the “From raster to point tool” and the grid cell values were assigned to the point layer. (5) The required information was extracted from the point layer to a data table, then the population was counted(Tewari & Manning., 2017; Holt et al., 2018).

The distribution of the rural population after China's construction of the Algeria expressway is shown in Fig. 7. The rural population within a 2 km buffer zone of the Algeria Cherchell Ring Expressway in 2009, 2011, 2013, 2015, 2017 and 2019 numbered 37,761, 39,581, 40,282, 42,964, 44,265, and 46,015 people, respectively. For the Algeria 53 km north-south highway, it was 31,842, 35,168, 35,246, 35,681, 36,883, and 37,950. For the Algeria Tipaza highway, it was 63,729, 67,419, 72,200, 74,117, 77,531, and 81,050, respectively. For the Algeria Begaya-Haniff highway, it was 133,481, 136,392, 140,084, 144,698, 148,286, and 152,217, respectively. For the

Algeria East-West Expressway (the west and middle sections) it was 847,763, 878,946, 921,606, 962,721, 1,009,783, 1,050,031 people, respectively.

The population of the Algeria Cherchell Ring Expressway is gradually increasing as shown in Table 4. Before the construction in 2011-2013, the growth rate was 1.77%. The population increased rapidly after the start of construction and was 6.66% in 2015. Population growth during the construction period was slower, dropping to 3.03%, and then increased afterward. From the start of construction to two years later, there was an increase of 5,733 people. The population growth rate within 2 km of the 53 km North-South Expressway decreased by 0.22% in 2013. After the start of construction, it gradually increased in 2017. After construction, the growth will be slower. The 53 km north-south expressway in Algeria will increase by 3782 people from the start of construction to the second year after construction. The growth rate of the Bekaya-Haniff connection line of Algeria from pre-construction in 2011 to construction in 2015 gradually increased to 3.29%, the growth rate in 2015-2017 fell to 2.48%, and the growth rate after construction was 2.65%. The population increased by 15,825 during the Bekaya-Haniff Expressway construction period.

As shown in Table 5, the population near the Tipaza expressway decreased. After the project started, the growth rate increased rapidly to 5.84%. During the construction process, the population growth rate dropped to 5.79%. After construction, the growth rate reached 7.09% two years later in 2013. The growth rate dropped to 2.66% from 2013 to 2015, and the population increased by 13,905 from the start to the end of construction. The growth rate of the Algeria East-West Expressway gradually increased from 2005 to 2009 to 6.36%. During the construction process, the population growth rate dropped to 3.68%. After completion of construction, the population growth rate was 4.85%. The population increased by 156,755 people during the East-West Expressway construction period. China's construction of five expressways in Algeria has increased the rural population in the 2 km buffer zone by 196,000 in the eight years of construction. By 2019, the population increased by 252,687, accounting for 9.16% of the rural population. In 2009, 2011, 2013, 2015, 2017, 2019, the rural population in the 2 km buffer zone accounted for 4.97%, 4.80%, 4.87%, 4.89%, 4.90%, and 4.86% of the total rural population, respectively.

Large area range HRSL population raster data statistics results

Tikhramtath town is located at the beginning of the Begaia Expressway and is the closest town to it. The town’s buildings are densely concentrated. The building numbers increased significantly

in 2011, 2015, 2017, and 2019, making the town particularly suitable for small-area case selection.

The large-area HRSL population raster data analysis method is used the nearest neighbor method to calculate the size of a single grid pixel. Then, by using the ARCGIS function of regional statistical analysis, all the HRSL population raster grid pixel values are tabulated and, finally, the sum of all pixel values is calculated.

The distribution of HRSL raster data for the rural population living within 2 km of an expressway in 2015 is shown in Fig. 8. The populations of the Algeria East-West Expressway, Bejaia Expressway, Tibza Expressway, North-South Expressway, and Cherchell Ring Expressway were 911,549, 127,471, 71,411, 30,583 and 41,657, respectively, accounting for approximately 4.12% of the 2015 rural population.

The population living within 2 km of the East-West Highway was the largest of the five highways, with a total population of 1,208,199, as shown in Table 6. The population distribution was closely related to the geography of Algeria. The northern part of Algeria comprises the coastal plains and hills of the Mediterranean coast, the central part is the Tele Atlas Mountains and Sahara Atlas Mountains, and the southern part of the Sahara desert is largely uninhabited.

Monitoring results of population estimation method for NDBI building area in the middle area

Fig. 9 shows that the building areas within 2 km of the Bekaya-Haniff Expressway in 2011, 2015 and 2019 were 15.84 km2, 17.77 km2, and 21.77km2, respectively in Algeria. By sampling 100 buildings to determine that the mean single building area is 290 m2, the rural populations in 2011, 2015 and 2019 are estimated to be 273,118, 306,430 and 375,408, respectively. They accounted for 15.23%, 16.65%, and 19.64% of the rural populations of Begaia, Buvira, and Boumerdes provinces, respectively.

The rural population of the Bekaya-Haniff Expressway in Algeria had the largest population growth rate in 2019 of 22.51%. Among them, the Tahalacht Industrial Zone in the northern part of the expressway, the Beni Mansour and the Tikhramtath town in the southern region, the Tala lbir town in the central region, Sidi Elash and Sidi Ayad have increased significantly.

Estimated population by remote sensing monitoring of a small area

Tikhramtath town is located at the beginning of the Begaia Expressway, the closest to the Begaia Expressway, and the towns and buildings are concentrated. The buildings increased significantly in 2011, 2015, 2017 and 2019, making it particularly suitable for small-area case selection.

The size of the building was vectored as a polygon feature by ArcGIS, then the ArcGIS tool "Calculate geometry" was used to calculate the area of the building. According to the 0.24-m high-resolution multi-time-series remote sensing image map, the number of building layers was compared with the image data of different periods. The number of layers of a single building was determined from the remote sensing image map. Finally, the layers of all buildings in Tikhramtath town were counted(Saadaoui et al., 2019).

A small area containing the town of Tikhramtath, within 2 km of the Bejay-Hanif Expressway in Algeria (before, during and after construction) was selected for demographic analysis. A map of the building distribution is shown in Fig. 10. The population of Tikhramtath town in 2011, 2015, 2017 and 2019 was 1,790, 2,785, 3,365 and 3,970, respectively, accounting for 0.29%, 0.35%, 0.52%, and 0.60% of the total rural population in Buvira.

From the statistical chart, the size of buildings in the town of Tikhramtath within 2 km of the Bekaya-Hanif Expressway, the floor height, and the population of each floor of each building were estimated. The population of the Tikhramtath town in 2015, 2017 and 2019 is shown in Table 7. The growth rates in 2015, 2017 and 2019 were 55.59%, 20.83%, and 15.01%, respectively. The increase in population was mainly due to the construction of the Bekaya-Haniff Expressway.

Discussion

Analyse and compare

(1)WorldPop and HRSL population statistics were used to compare regions around five highways built in Algeria in 2015. The results are shown in Table 8.

The table shows that there is a small difference between the WorldPop demographic data and the HRSL population data. The rural populations of the five road buffers differed by 1307, 5098, 17,227, 2706, and 51,172.

(2) Comparison of the World Bank's WorldPop population statistics method, the NDBI building area estimation method, and the HRSL population statistics method for the 2 km population of the Begaya-Hanif Expressway.

This paper uses the World Bank's WorldPop population statistics, the NDBI building area estimation method, and HRSL population statistics to analyze the demographics of the Begaia-Haniff Expressway in Algeria. The results are shown in Table 9.

According to the statistics, the WorldPop population data and NDBI building area population estimates for 2011, 2015, and 2019 are quite different. The differences are 136,726, 161,732 and 223,191, respectively. The difference between the WorldPop and HRSL population statistics is small, at 17,227. The NDBI building area population estimation method is subjective, and the total population can only be judged roughly, resulting in large errors. Worldpop demographics and HRSL demographics are also due to the small difference in statistical results due to resolution issues.

(3) Table 10 compares the WorldPop population data and the small area remote sensing monitoring method for Tikhramtath town.

Table 10 shows that the results of the three methods for Tikhramtath town are quite different. The remote sensing monitoring visual interpretation method and WorldPop population statistics differed by 1782, 2766, 3349 and 3853, respectively. The remote sensing monitoring visual interpretation method differed from the HRSL population statistics by 2,690 people. The WorldPop population statistics are obviously inconsistent with the actual situation, while the remote sensing monitoring visual interpretation method locates the added buildings.

Precision verification

We used GHS Population Grid data for accuracy verification. The GHS Population Grid is made up of residential population estimates for target year 2015 provided by CIESIN GPWv4

(Gridded Population of the World, now in its fourth version). The estimates were disaggregated from census or administrative units into grid cells, according to the distribution and density of built-up areas as mapped in the GHSL global layer for the corresponding epoch. An accuracy assessment table is shown in Table 11.

In the accuracy comparison, lower %RMSE values indicate higher accuracy. The accuracy of the WorldPop population data in the large area was 89.99%, which is slightly higher than the 81.02% accuracy of the HRSL population data. WorldPop population data was also most accurate in the middle region. The NDBI building area estimates are subjectively influenced by people and had the lowest accuracy of 2.58%. The accuracy of the population data for Tikhramtath town (in the small area) was generally low and that of the HRSL population data was higher than that of the other two groups, at 12.34%.

Conclusions

The five highways built by China have led to increases in the rural populations on both sides of the roads. Cherchell Ring Expressway, the 53 km North-South Expressway, Tipaza Expressway, Bekaya-Haniff Link Expressway, and East-West Expressway have driven rural population increases of 5733, 3782, 13,905, 15,825 and 196,000, respectively. The population of the 2 km buffer zone of the Bekaya-Haniff Expressway in Algeria in 2011, 2015 and 2019 was 273,118, 306,430, and 375,408, respectively. The population of Tikhramtath in 2011, 2015, 2017 and 2019 was 1790, 2785, 3365, and 3970, respectively.

From large areas to small areas, different methods are suitable for road-wide demographic analysis: large- and medium-area demographics are suitable for WorldPop population statistics; while small-area demographics can use HRSL population raster data.

The WorldPop dataset is updated once per year. HRSL population data is only available from 2015 and it is not possible to obtain data on populations within 2 km of roads every year. Although NDBI building area estimation data and remote sensing visual interpretation estimation data are of low precision, they are not affected by slow population data update , and can estimate the population according to remote sensing images in time.

Conflicts of Interest: The authors declare they have no conflicts of interest.

Author Contributions: Zhanhai Jia wrote the paper; Mingquan Wu and Zheng Niu gave comments and suggestions on the manuscript and checked the writing; Bin Tang and Yuxuan Mu analyzed the data.

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Figure 1

Study area location maps

(~~A~~) Tipaza Expressway, (B) Cherchell Ring Expressway, (C) North-South Expressway, (D) all five highways, (E) East-West Expressway, (F) Bekaya Expressway

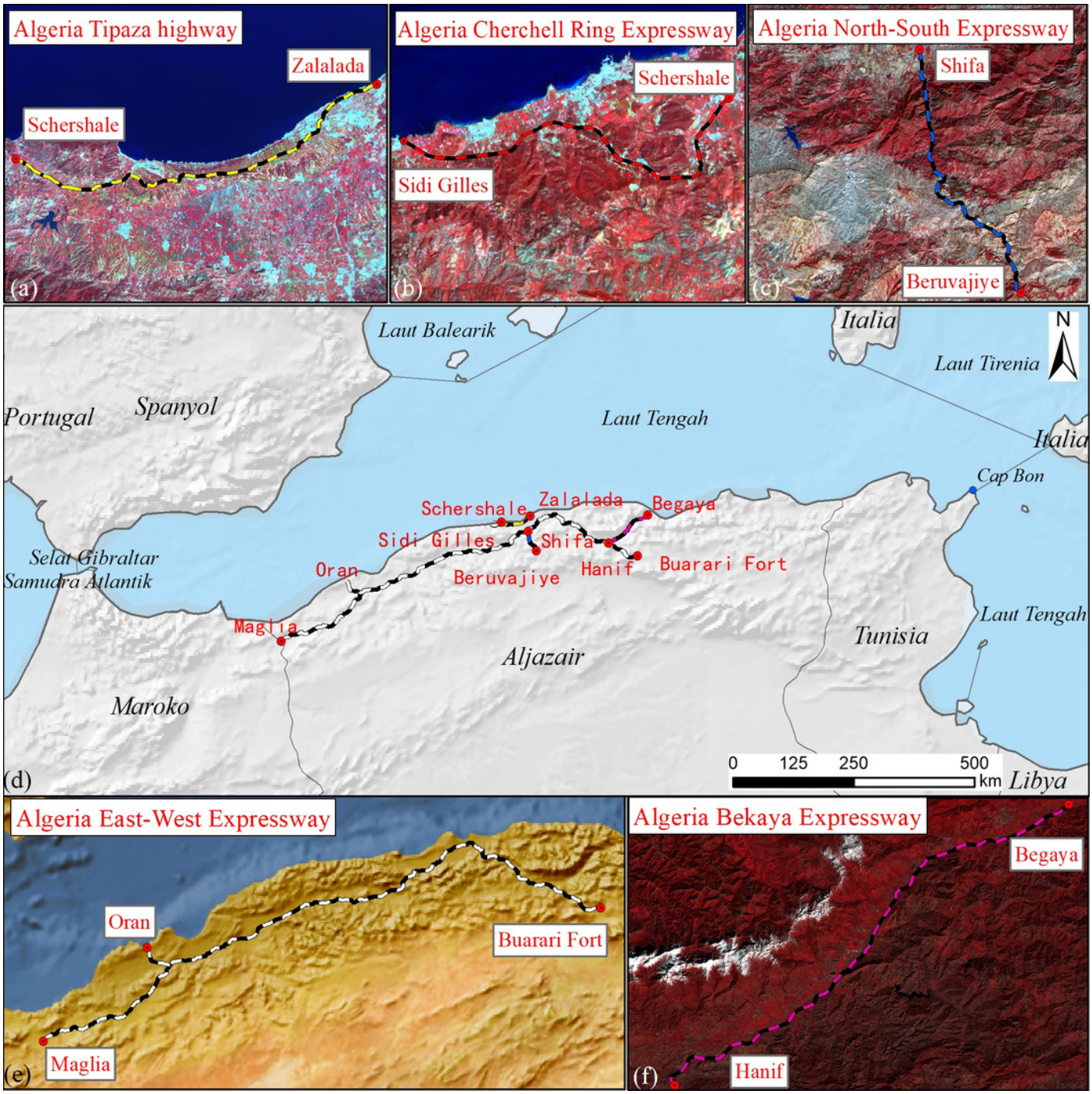
Algeria Tipaza highway
Zalalada
Schershale
(a)
Algeria Cherchell Ring Expressway
Schershale
Sidi Gilles
(b)
Algeria North-South Expressway
Shifa
Beruvajiye
(c)
Laut Balearik
Italia
N
Laut Tirenia
Portugal
Spanyol
Laut Tengah
Italia
Cap Bon
Schershale
Zalalada
Begaya
Sidi Gilles
Shifa
Selat Gibraltar
Samudra Atlantik
Oran
Beruvajiye
Hanif
Buarari Fort
Laut Tengah
Maglia
Tunisia
Aljazair
Maroko
0 125 250 500
km
Libya
(d)
Algeria East-West Expressway
Oran
Buarari Fort
Maglia
(e)
Algeria Bekaya Expressway
Begaya
Hanif
(f)

Figure 2

Flow chart of the three methods

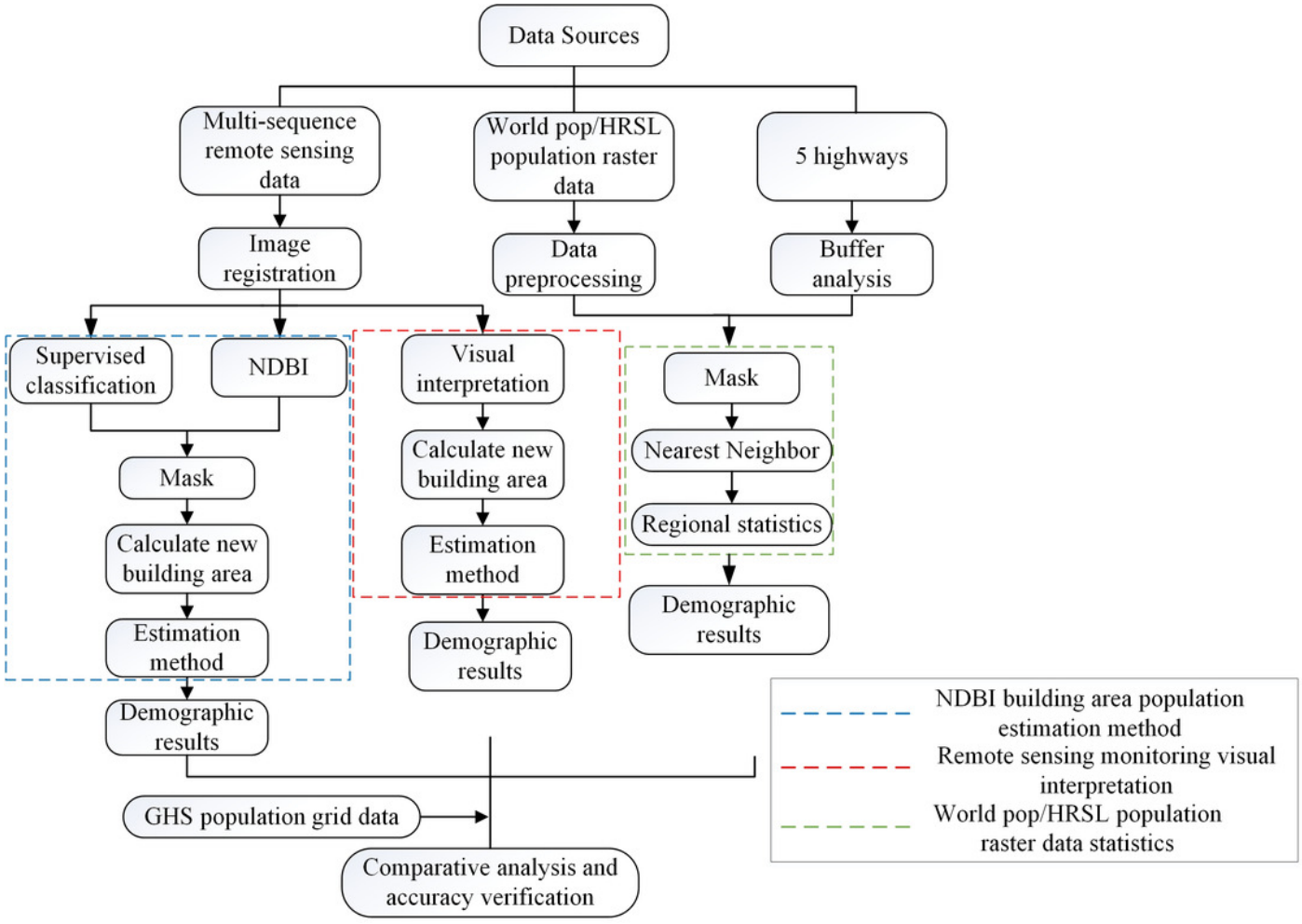

Figure 3

2011, 2015, 2019 NDBI

(A) Schematic diagram of the local study area, (B) 2011 Landsat remote sensing image map, (C) 2011 NDBI map, (D) 2015 Landsat remote sensing image map, (E) 2015 NDBI map, (F) 2019 Landsat remote sensing image map, (G) 2019 NDBI map

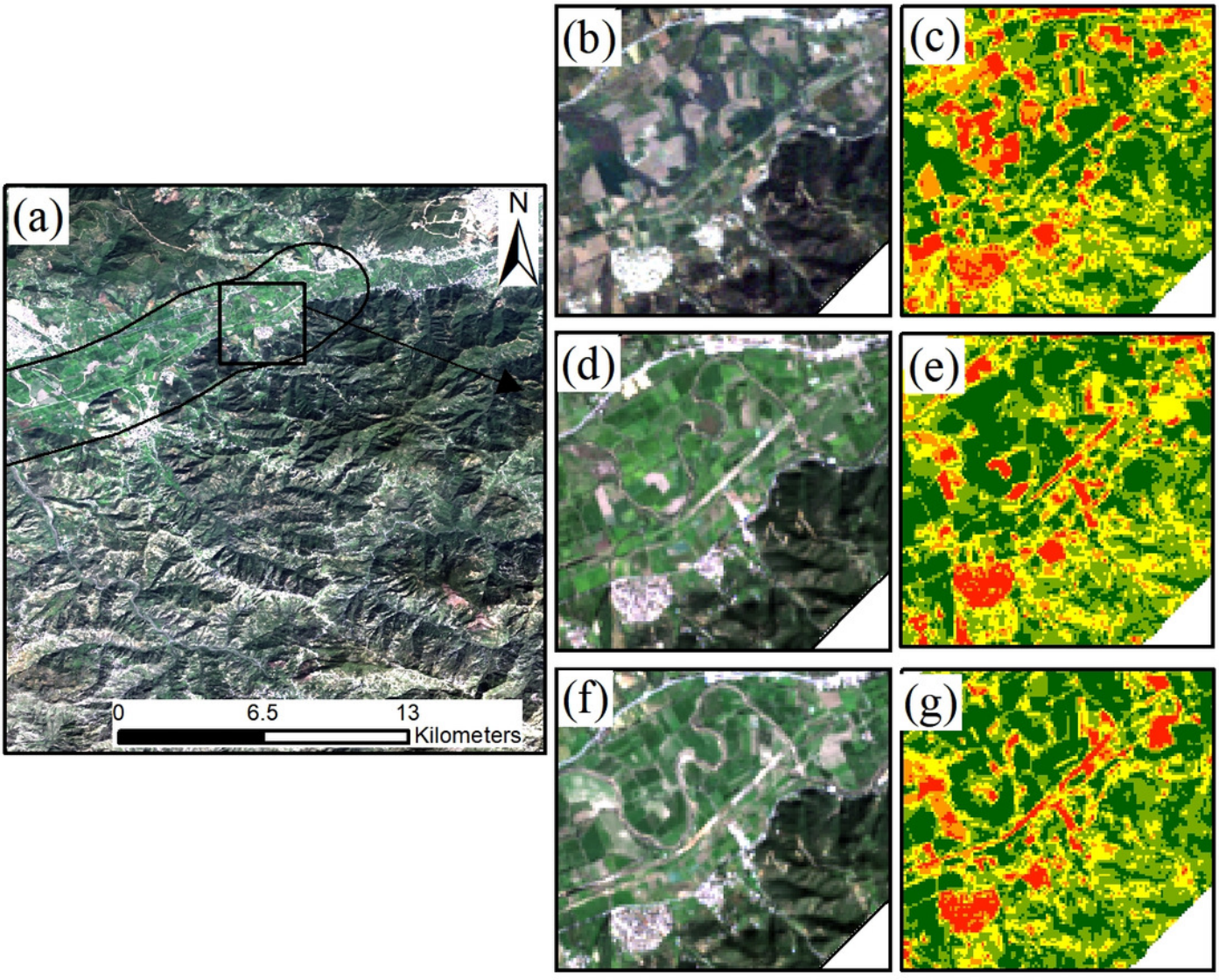

Figure 4

Algerian urban population map

(A) 2009, (B) 2011, (C) 2013, (D) 2015, (E) 2017, and (F) 2019

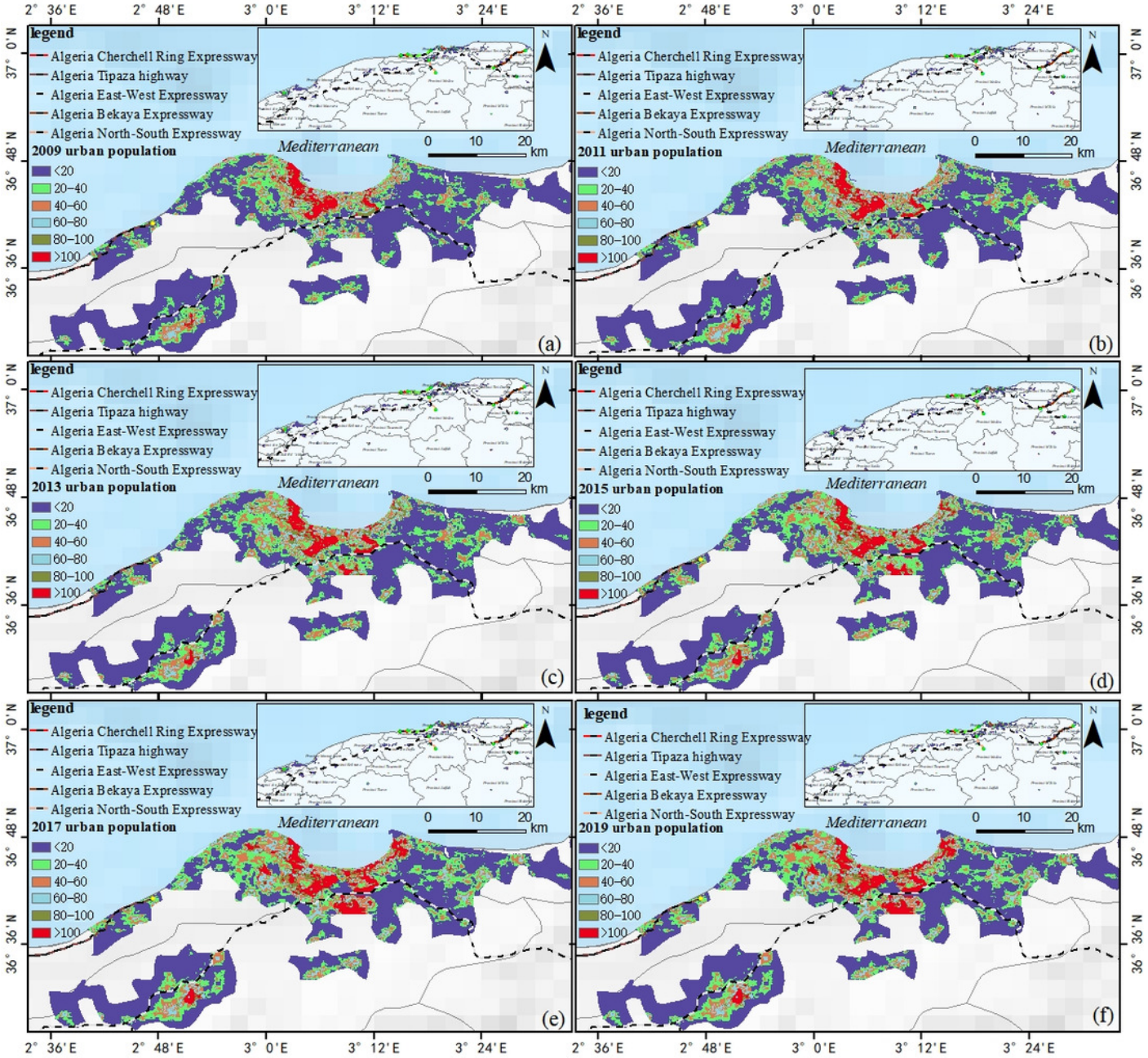

Figure 5

Demographic changes in the provinces of Algeria

(A)Population in 2009□2011 and 2013, (B) Growth rate in 2011 and 2013

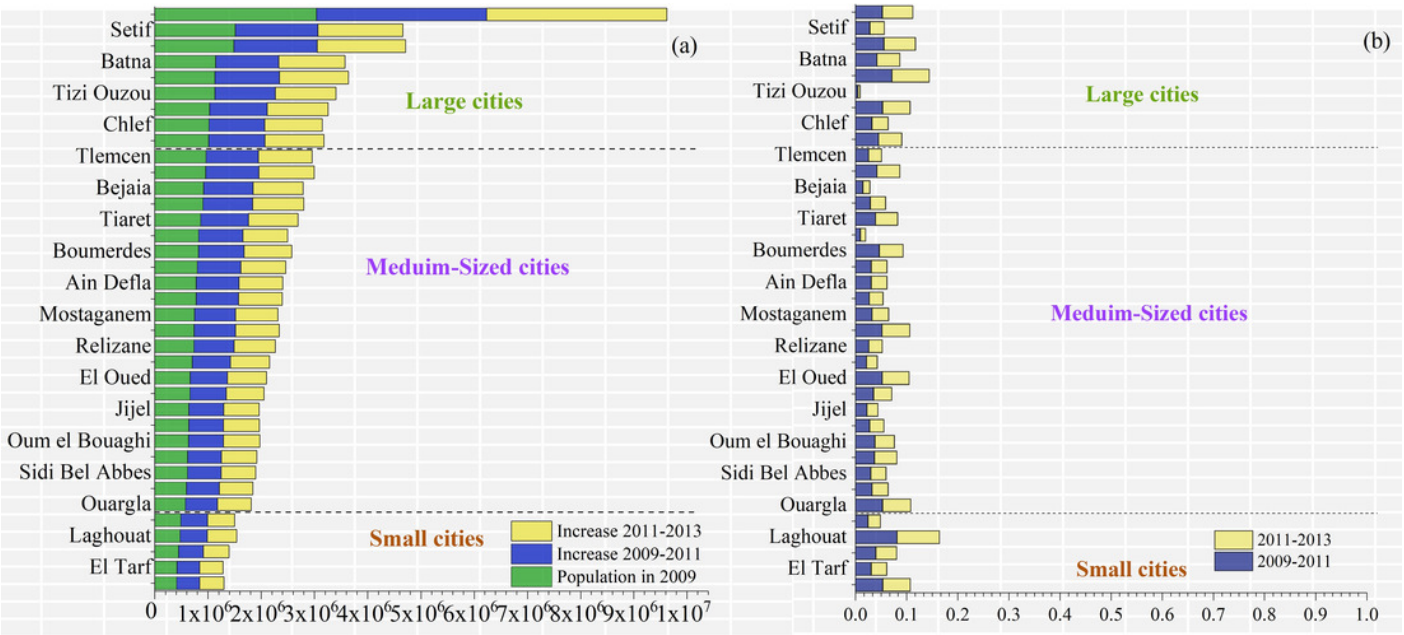

Figure 6

Demographic changes in the provinces of Algeria

(A)Population in 2015□2017 and 2019, (B) Growth rate in 2017 and 2019.

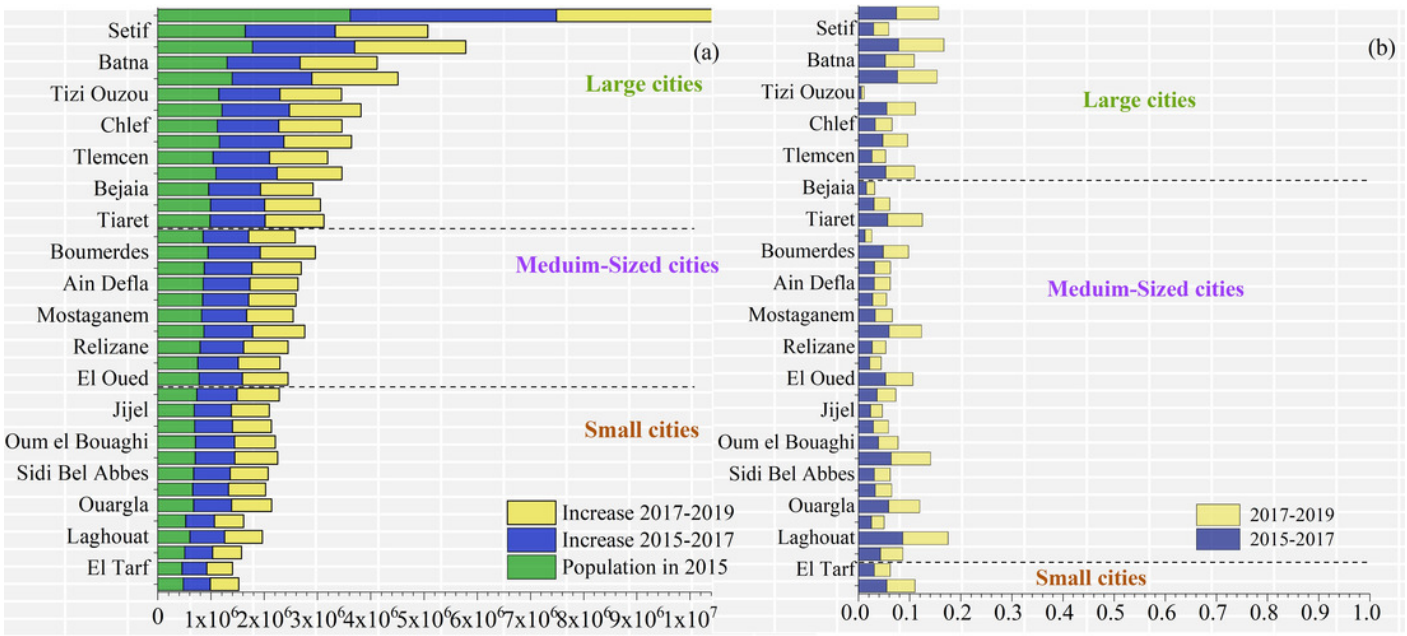

Figure 7

Population distribution within the 2 km buffer zone of five Algerian highways constructed by China

(A) 2009, (B) 2011, (C) 2013, (D) 2015, (E) 2017, and (F) 2019.

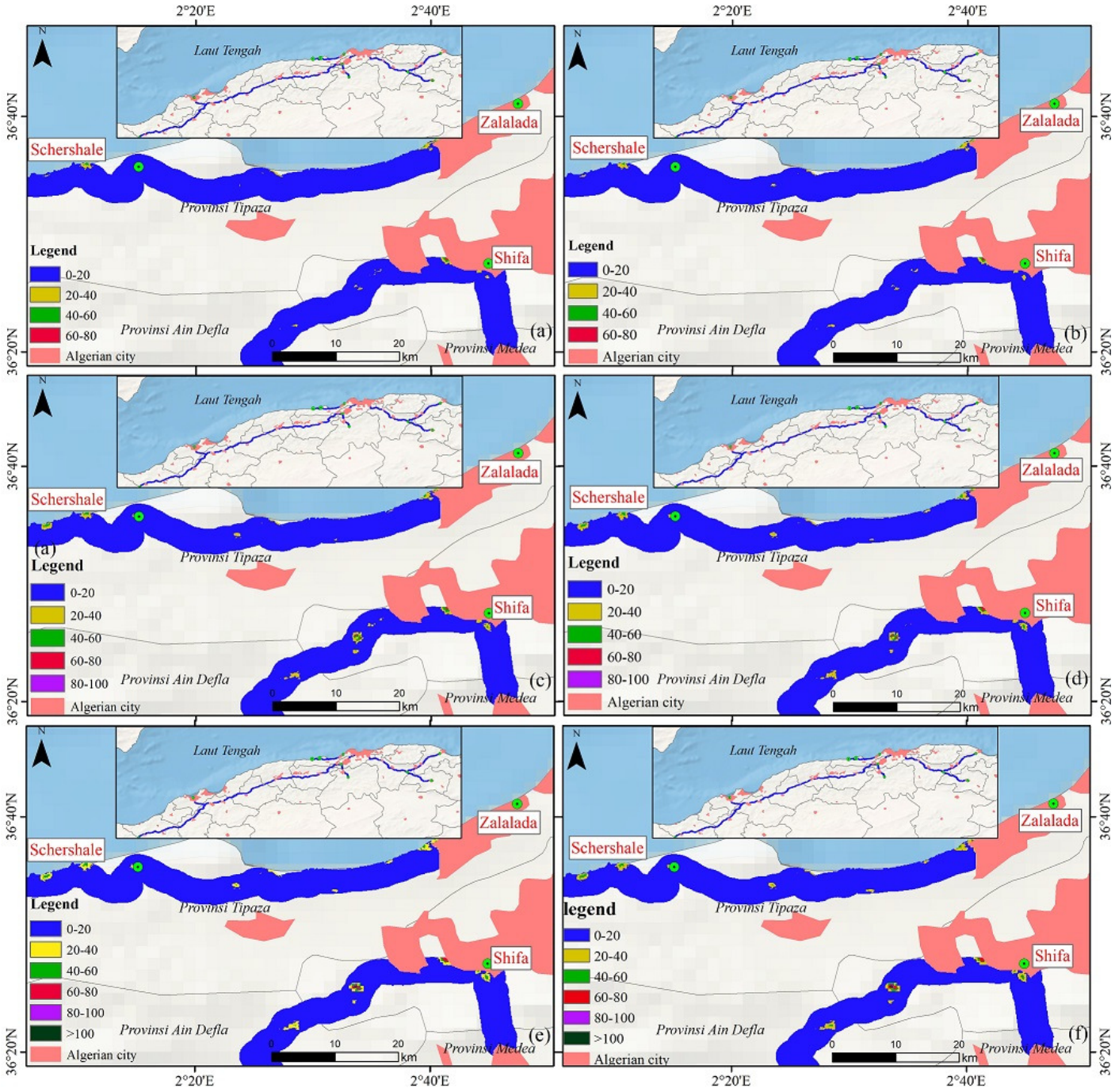
2°20'E
2°40'E
36°40'N
36°20'N
N
Laut Tengah
Zalalada
Schershale
Provinsi Tipaza
Shifa
Provinsi Ain Defla
Provinsi Medea
0 10 20 km
(a)
(b)
(c)
(d)
(e)
(f)
Legend
0-20
20-40
40-60
60-80
80-100
>100
Algerian city
legend

Figure 8

Distribution of rural HRSL population data within 2 km of highways in 2015

(A) Bekaya Expressway, (B) Tipaza Expressway, (C) Cherchell Ring Expressway, (D) North-South Expressway, (E) East-West Expressway.

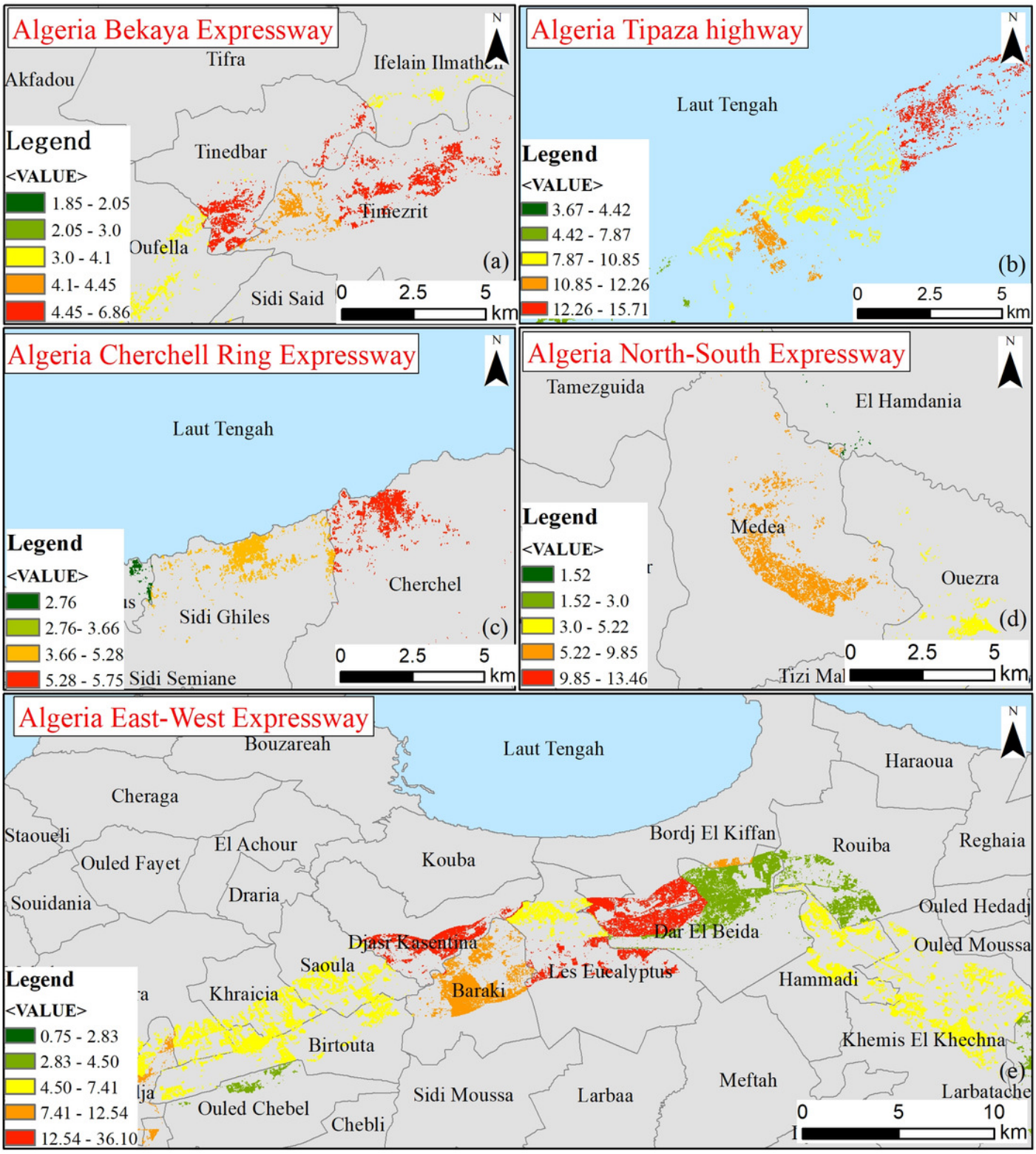
Algeria Bekaya Expressway
Tifra
Ifelain Ilmathen
Akfadou
Tinedbar
Timezrit
Oufella
Sidi Said
Legend
<VALUE>
1.85 - 2.05
2.05 - 3.0
3.0 - 4.1
4.1- 4.45
4.45 - 6.86
(a)
0 2.5 5 km
Algeria Tipaza highway
Laut Tengah
Legend
<VALUE>
3.67 - 4.42
4.42 - 7.87
7.87 - 10.85
10.85 - 12.26
12.26 - 15.71
(b)
0 2.5 5 km
Algeria Cherchell Ring Expressway
Laut Tengah
Cherchel
Sidi Ghiles
Sidi Semiane
Legend
<VALUE>
2.76
2.76- 3.66
3.66 - 5.28
5.28 - 5.75
(c)
0 2.5 5 km
Algeria North-South Expressway
Tamezguida
El Hamdania
Medea
Ouezra
Legend
<VALUE>
1.52
1.52 - 3.0
3.0 - 5.22
5.22 - 9.85
9.85 - 13.46
(d)
0 2.5 5 km
Algeria East-West Expressway
Bouzareah
Laut Tengah
Haraoua
Cheraga
Staoueli
El Achour
Ouled Fayet
Kouba
Bordj El Kiffan
Rouiba
Reghaia
Souidania
Draria
Ouled Hedadj
Djasr Kasentina
Dar El Beida
Ouled Moussa
Saoula
Les Eucalyptus
Hammadi
Khraicia
Baraki
Birtouta
Khemis El Khechna
Meftah
Sidi Moussa
Larbaa
Larbatache
Ouled Chebel
Chebli
Legend
<VALUE>
0.75 - 2.83
2.83 - 4.50
4.50 - 7.41
7.41 - 12.54
12.54 - 36.10
(e)
0 5 10 km

Figure 9

NDBI extraction of rural buildings within 2 km of the Bekaya-Haniff Expressway

(A) 2011, (B) 2015, and (C) 2019.

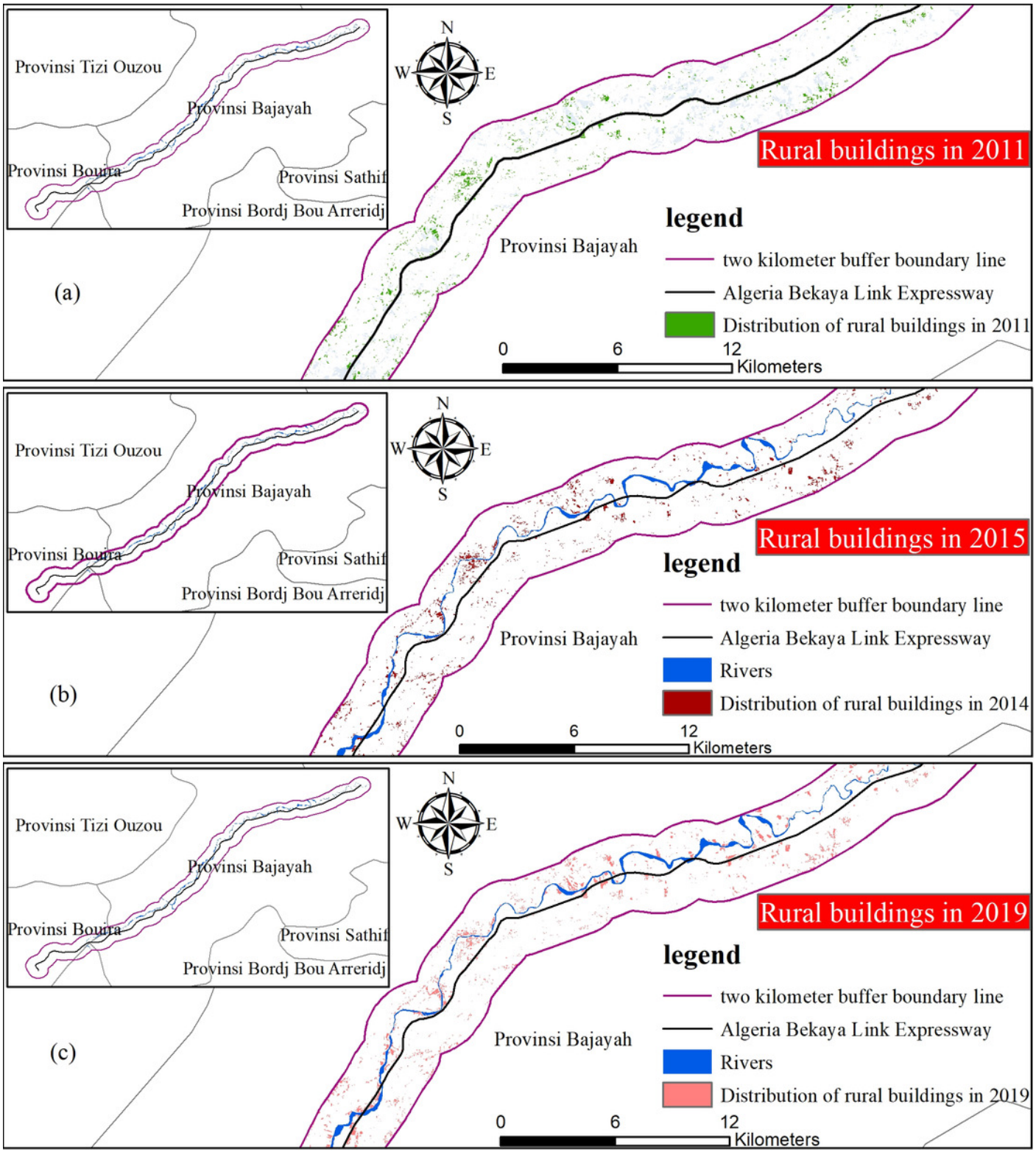
Provinsi Tizi Ouzou
Provinsi Bajayah
Provinsi Bouira
Provinsi Sathif
Provinsi Bordj Bou Arreridj
N
W
E
S
(a)
Rural buildings in 2011
legend
two kilometer buffer boundary line
Algeria Bekaya Link Expressway
Distribution of rural buildings in 2011
0
6
12
Kilometers
(b)
Rural buildings in 2015
legend
two kilometer buffer boundary line
Algeria Bekaya Link Expressway
Rivers
Distribution of rural buildings in 2014
(c)
Rural buildings in 2019
legend
two kilometer buffer boundary line
Algeria Bekaya Link Expressway
Rivers
Distribution of rural buildings in 2019

Figure 10

Remote sensing monitoring of the building distribution in Tikhramtath town

(A) 2011, (B) 2011 and 2015, (C) 2011, 2015 and 2017, and (D) 2011, 2015, 2017, and 2019.

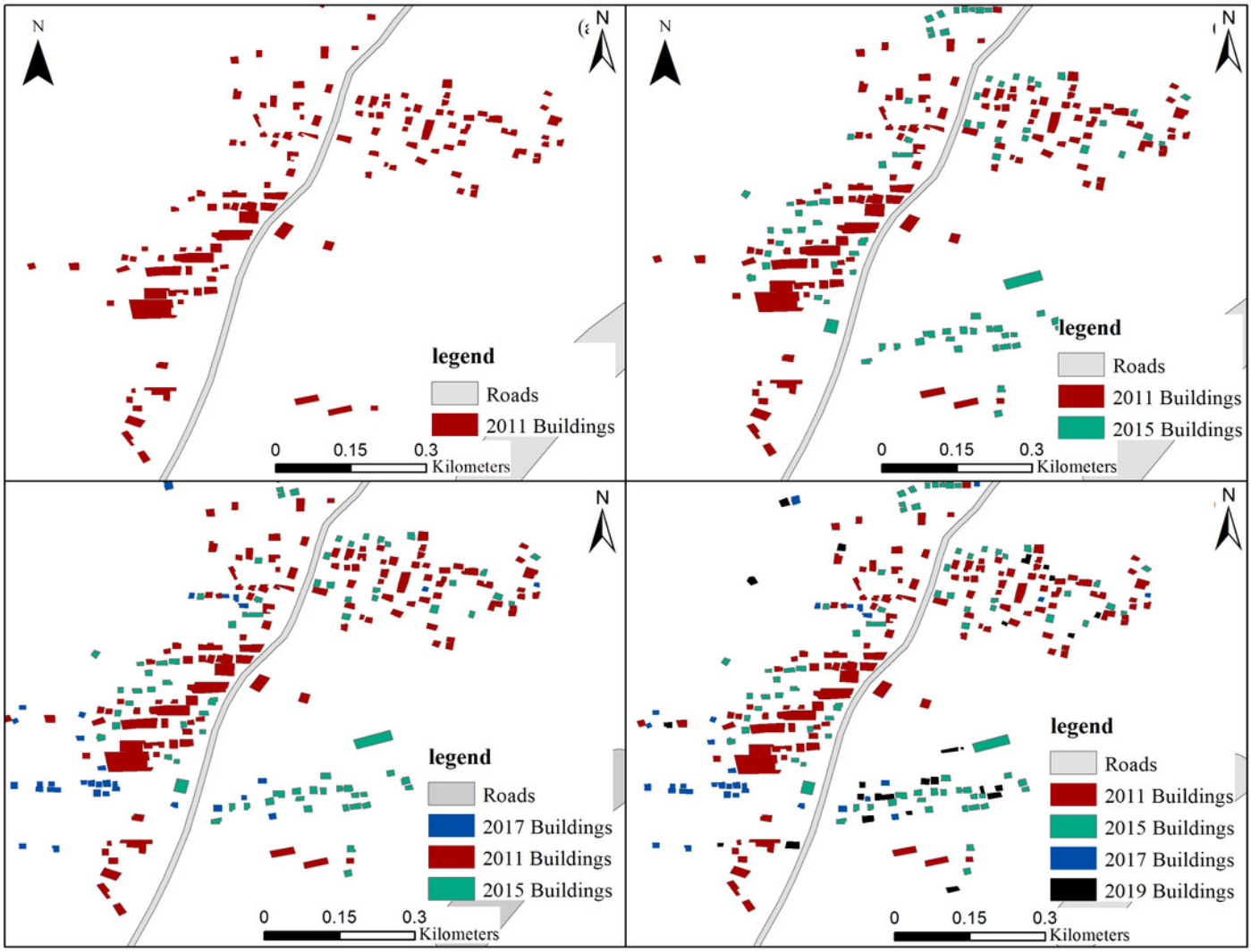

Table 1(on next page)

China's Belt and Road Expressway in Algeria

1 Table 1. China's Belt and Road Expressway in Algeria.

Continent	Country	Highway name	Chinese company	Line length (km)	Construction start year	Construction end year or duration	Mode of cooperation (investment, construction, acquisition)
Africa	Algeria	East-West Expressway	China Railway Construction 17th Bureau, China International Trust, and Investment	528	2006	2012	Joint construction
Africa	Algeria	Tipaza Expressway	China Construction Fifth Bureau	48	2008	2011	Contract construction
Africa	Algeria	North-South Expressway	China Construction Corporation	53	2012	2015	Joint construction
Africa	Algeria	Cherchell Ring Expressway	China Construction Corporation	17	2014	2018	Contract construction
Africa	Algeria	Bekaya Expressway	China Construction Corporation	100	2013	2017	Contract construction

2

Table 2(on next page)

Data sources.

1 Table 2. Data sources

Data	Source	Dates	Internet link	Spatial resolution
World population raster data	HRSL	2015	https://www.ciesin.columbia.edu/data/hrsl/#data	30 m
World population raster data	WorldPop	2010-2019	http://www.worldpop.org.uk/	100 m
World population raster data	GHS	2015	https://ghslsys.jrc.ec.europa.eu/datasets.php#2016public	250 m
Urban area	Natura Earth	2018	http://www.naturalearthdata.com	10 m
Remote sensing image	Landsat 5 and Landsat 8	2011, 2015, 2019	http://earthexplorer.usgs.gov	30 m
Administrative division map	GADM	2018	https://gadm.org/download_country_v3.html	Level-City

2

Table 3(on next page)

Supervised classification sample selection table

1 Table 3. Supervised classification sample selection table

Category	Meaning	Legend sample	Verification photo
Urban and rural areas, industrial, mining, and residential land	Land for buildings and structures, including special land for commercial, industrial, and mining purposes		
Woodland	Forests, shrubs, bamboo, and other forestry land		
Arable land	Mature cultivated land, newly opened wasteland, leisure land		
Bare land	Bare ground without vegetation or structures		

2

Table 4(on next page)

Statistics of highway populations

1 Table 4. Statistics of highway populations

Year	Muirdale Ring Road population	Growth rate	North-South Expressway population	Growth rate	Begaia Expressway population	Growth rate
2011 (before construction)	39,581	4.82%	35,168	10.45%	136,392	2.18%
2013 (before construction)	40,282	1.77%	35,246	0.22%	140,084	2.71%
2015 (under construction)	42,964	6.66%	35,681	1.23%	144,698	3.29%
2017 (under construction)	44,265	3.03%	36,883	3.37%	148,286	2.48%
2019 (after construction)	46,015	3.95%	37,950	2.89%	152,217	2.65%

2

Table 5(on next page)

Statistics of the highway populations

1 Table 5. Statistics of the highway populations

Year	Tebza 48 km highway population	Growth rate	East-West Expressway population	Growth rate
2005 (before construction)	60,320	3.70%	764,851	3.61%
2007 (before construction)	60,212	-0.18%	797,051	4.21%
2009 (under construction)	63,729	5.84%	847,763	6.36%
2011 (under construction)	67,419	5.79%	878,946	3.68%
2013 (after construction)	72,200	7.09%	921,606	4.85%

2

Table 6(on next page)

HRSL population statistics within 2 km of highways in 2015

1 Table 6. HRSL population statistics within 2 km of highways in 2015

Highway	Rural population	Urban population	Total population
Cherchell Ring Road	41,657	0	41,657
North-South Expressway	30,583	19,844	50,427
Begaia Expressway	127,471	19,136	146,607
Tibza 48 km highway	71,411	17,336	88,747
East-West Expressway	911,549	296,650	1,208,199

2

Table 7 (on next page)

Population of Tikhramtath town according to building characteristics, 2011 – 2019

1 Table 7. Population of Tikhramtath town according to building characteristics, 2011 – 2019

Building area (m2)	2011			2015			2017			2019			Population per floor
	1-floor buildings	2-floor buildings	3-floor buildings	1-floor buildings	2-floor buildings	3-floor buildings	1-floor buildings	2-floor buildings	3-floor buildings	1-floor buildings	2-floor buildings	3-floor buildings	
0-150	18	0	0	31	0	0	37	0	0	42	0	0	5
150-300	57	4	0	124	6	1	145	11	1	159	11	1	10
300-600	28	3	0	34	3	0	42	3	0	58	3	0	15
>600	17	2	2	22	2	2	28	2	2	33	2	2	20
Total population	1790			2785			3365			3870			

2

Table 8(on next page)

WorldPop and HRSL population statistics

1 Table 8. WorldPop and HRSL population statistics

Region	WorldPop population statistics (persons)	HRSL population statistics (persons)
Cherchell Ring Expressway	42,964	41,657
North-South Expressway	35,681	30,583
Begaia Expressway	144,698	127,471
Tibza Expressway	74,117	71,411
East-West Expressway	962,721	911,549

2

Table 9(on next page)

WorldPop, NDBI and HRSL population statistics

1 Table 9. WorldPop, NDBI and HRSL population statistics

Time	WorldPop population statistics	NDBI building area population estimation method	HRSL population statistics
2011 (before construction)	136,392	273,118	
2015 (under construction)	144,698	306,430	127,471
2019 (after construction)	152,217	375,408	

2

Table 10(on next page)

WorldPop, Remote sensing, and HRSL population statistics

1 Table 10.WorldPop, Remote sensing, and HRSL population statistics

Time	WorldPop population statistics	Remote sensing visual interpretation	HRSL population data statistics
2011 (before construction)	8	1790	
2015 (under construction)	19	2785	95
2017 (under construction)	16	3365	
2019 (after construction)	17	3870	

2

Table 11(on next page)

Accuracy veri□cation table

1 Table 11. Accuracy verification table

Area	Expressway	Source	RMSE	%RMSE
Large area range	Cherchell Ring Expressway	WorldPop	26,516	10.01
	North-South Expressway			
	Begaia Expressway	HRSL	50,270	18.98
	Tibza Expressway			
	East-West Expressway			
Middle area	Begaia Expressway	WorldPop	10,516	6.78
		HRSL	27,743	17.87
		NDBI building area estimate	15,216	97.42
Small area	Tikhramtath town	WorldPop	751	97.53
		HRSL	675	87.66
		Remote sensing visual interpretation data	2015	261.69

2

3