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GIS for Urban Planning & Management Service – A case Study of Fathua Municipality in Patna District (Bihar, India)

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Abstract
The cities will probably continue expanding and expand, necessitating careful planning, management, and improvement of the current infrastructure. The supply of appropriate amenities is a major concern for planners. The primary goal of the research is to examine the rate of urbanization and its trends in the surrounding city or town, as well as to identify potential locations for future development. Infrastructure data (road, water supply, drainage, building) have been analyzed and digitized at 1:4000 scale using Google Earth. Density analysis was performed to understand the highest concentration of infrastructure within the study site. Highest population density is calculated for ward no. 8,9, 14, 15, 16, 21 and 22. The highest road density is calculated for ward no 5, 8, 9 and 12. Urban planners may now develop an expert decision support system targeted at different decision-making processes by using remote sensing and geographic information systems.

Keywords: Urban Panning, GIS, Infrastructure, Density Analysis

Introduction

Although urbanisation is an ancient phenomenon that has existed for millennia, it has evolved into a more complicated socio-economic process in modern times. Along with changing the social fabric and demographic structure, it also affects occupation, lifestyle, culture, and behaviour as more people move from rural to urban areas. In the years 2001 to 2011, Bihar had a marked acceleration in the rate of urban population expansion, adding 72 new towns to its urban landscape. Compared to 22.89% and 31.16% for all of India, Bihar's urbanisation rate has merely risen from 9.59% in 1981 to 11.29% in 2011 (https://mohua.gov.in/). It is important to note that Bihar's annual exponential growth rate (AEGR) from 2001 to 2011 was 3.06, whereas the average for all of India was 2.76 (Bhagat, 2018). Urbanisation in Bihar is mostly influenced by fertility. Rural-urban migration has a comparatively minor impact on Bihar's urbanisation trend (Parida, 2019). The urban system in

Bihar is characterised by connections between urbanisation and economic expansion. Many people become caught in the low urbanization/poor income trap.

The underlying collection of laws, regulations, and institutional frameworks that make geographical data accessible and available is referred to as "spatial data infrastructure" (SDI). The SDI offers a framework for spatial data discovery, appraisal, and application for consumers as well as manufacturers at all levels of government, the business sector, the private sector, academia, and people in general (Rahman et al., 2023). It includes geographic information and characteristics, as well as pertinent documentation, a method for classifying, displaying, and analysing the data, and a process for making the data accessible (Nogueras-Iso et al., 2005). The transmission of possibly infinite numbers of geographic data packets is made possible by an SDI. It is now well acknowledged that Geographical Information System (GIS) technologies may significantly contribute to the building of many types of infrastructure in an urban environment. The vast majority of choices made by local bodies at different levels are based on geographic and geographical analysis, with additional local criteria added through the use of Theme Specific Decision Support and Intelligent Systems. Beyond the realms of "what to do" and "how to do it," or in alphanumeric terms, "where to set up" (which is the best location) and "how to build up the infrastructure," the primary concerns for every urban planner involved in the construction of infrastructure over resource location are these two issues (Kumar and Jailia,2018). Both of these issues have a direct impact on business economics, and GIS, after weighing many ideas, offers acceptable and practical answers to these issues.

Building and maintenance expenditures may be monitored and controlled centrally thanks to physical mapping's integration with GIS's project management and budgeting tools (Whyte et al., 2016). A GIS-based maintenance management system that promotes effective activity planning and tracking of work tasks, staff, equipment, and costs associated with inventory allows administrators to monitor and report service operations. During inspections, problems might be found in the field, and the GIS can quickly generate new service requests for maintenance and repair. GIS will make it possible for project managers and other participants from a variety of backgrounds to learn about the project's status and make wise decisions (Irfan et al., 2021). GIS offers these groups a platform for communication and cooperation as well.

Urban Bihar has appallingly poor access to essential infrastructure services, including public transport, solid waste collection, piped sewage connected to latrines, and water delivery (Osra et al., 2022). The economic implications of inadequate urban infrastructure services are particularly substantial for Bihar. The majority of municipalities in Bihar lack the funds and technology necessary to gather emancipated town-level statistics to operate a database. In this regard, present study aims to assess the geographical variation of infrastructure distribution in Fathua municipality of Bihar (India) and aids to demarcate the probable sites for better planning and improvement.

Study area

A satellite town in the Patna district of Bihar, Fatuha—also spelt Fatwah or Fatwa—is part of the planned Patna Metropolitan Region. The Ganges and Punpun Rivers meet at Fatuha. The city's southern borders are formed by the Dhoba and Mahatmain Rivers, which were the primary branches of the River Falgu until they disappeared into the "Taal" region. Due to its many river drainage systems, including the Ganges and Punpun, Fatuha has excellent soil. Crops of every kind are cultivated in great quantities. Onions in particular are widely produced in Fatuha. Its location in the middle Ganges basin's lower reaches gives it a typical humid monsoon climate.

Materials & Methods

Data collection and processing

Population data is collected from the Fathua Municipal office. Secondary maps of administrative boundaries, existing water networks, power supply networks were collected. All the maps were geo-referenced in Universal Transverse Mercator Projection System with World Geodetic System (WGS) 84 datum. Using an accumulation of vector (point, line, and polygon) coordinates, the geometry for a feature is saved as a shapefile (.shp). In order to add features and attributes independently, each shapefile has been included to a project map as a layer by selecting "New Layer" from the View option individually. The municipal and ward boundaries were digitized through heads-up digitizing method. The drainage network of the study area is digitized from the Google Earth image. Using the required vector and advanced editor functions, features were created on a map. Where appropriate, new fields were created, and attribute data for a feature was instantly inserted into a table after a feature was generated.

Utility mapping

The existence of infrastructure (which includes water supply, road infrastructure, communication facilities, dwelling types, and the presence of power supply network facility) has a major impact on the quality of life in metropolitan areas. Road network, buffer, and connectivity studies may be used in a GIS to estimate the physical location of different services within a certain distance. The primary input data is given as spatial vectors that are clearly organised into layers that include municipal and ward boundaries, building footprints, water and electricity supply networks, road networks. The population density of the study area is calculated based on the ratio between number of population and ward area. Topological correction has been done based on tolerance value 0.001 to remove the overshoot and undershoot. The primary input data is given as spatial vectors that are clearly organised into layers that include building footprints, boundaries, water and electricity supply networks, road networks, and so on, each with unique qualities.

Density calculation

The Line Density tool is used to calculate the density of linear features (such as roads, drainage systems, water supplies, and power supply networks) of each output raster cell (Silverman, 1986). Each square kilometre of the research region's area is divided into length units to compute density. In principle, a search radius (50m) is used to construct a circle around the center of each raster cell when utilizing line density. Each linear segment's fraction that falls inside the circle is multiplied by the number of times it occurs. The sum of these numbers is divided by the circumference of the circle.

$$Density = \frac{(L_1 \, x \, W_1) + (L_2 \, x \, W_2)}{(Area \; of \; Circle)}$$

Whereas,

- The lengths L_1 and L_2 denote the segments of each line that are included within the circle.
- The corresponding weight field values are W_1 and W_2. In the event that a population field other than NONE is utilized, the line's length is calculated by multiplying its true length by the value of the weighted field.

Results

Population Density

There were 50,961 people living in Fatuha as per the 2011 India Census, with men making up 52.9% of the population and women making up 47.1%. The average literacy rate of Fatuha is 70.2%, which is higher than the 59.5% average for the country. The literacy rate for men is 78% whereas it is only 59% for women. In the study area, the highest population density is calculated as 75103 persons per sq km and the lowest population density is calculated as 2396 persons per sq km. The average population density of the municipality is calculated as 24,997±16947 persons per sq km. Based on the estimated population density, the study area is divided into five categories, (i) <5000, (ii) 5001 – 10000 persons per sq km, (iii) 10001 – 20000 persons per sq km, (iv) 20001 – 30000 persons per sq km and (v) >30001 persons per sq km. Figure 2 portrays the geographical variation of population density of Fathua municipality. Ward no. 8, 9, 12, 14, 15, 18, 20 and 21 calculated the highest population density. Ward no. 24 and 27 recorded the lowest population density. Ward no. 1, 4, 6, 22 and 23 estimated the medium population density.

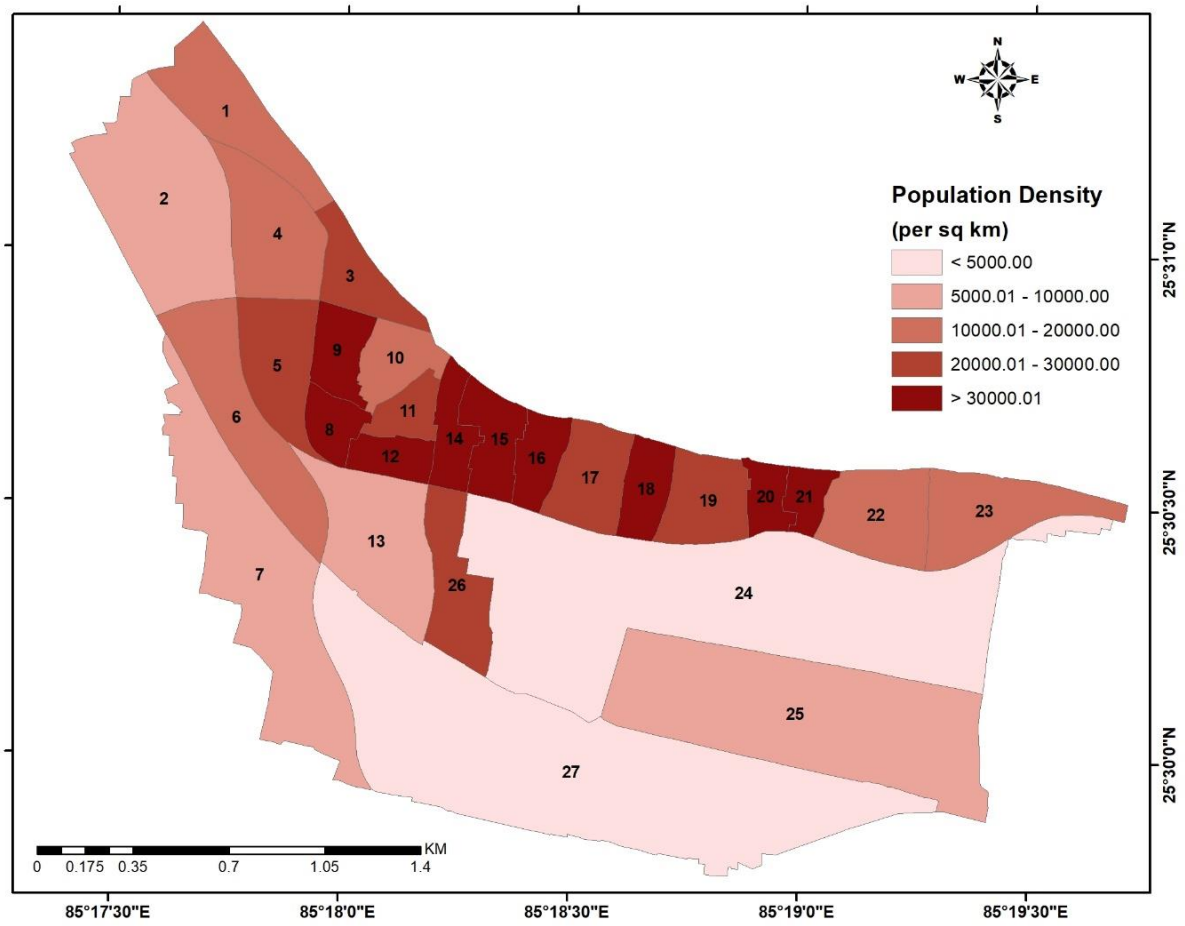

Figure 1: Geographical distribution of population density in Fathua municipality

Drainage network

In the study area, river Ganges flows in the extreme north. Most of the drainage are open in the study area and are distributed in northern part of the municipality (Figure 3). Very few drainages are observed in south and north-east of the study area. There are few low laying areas (locally called as chaurs) in the south and central of the study area. There is no drainage network is observed in Ward no. 1, 7 and 25

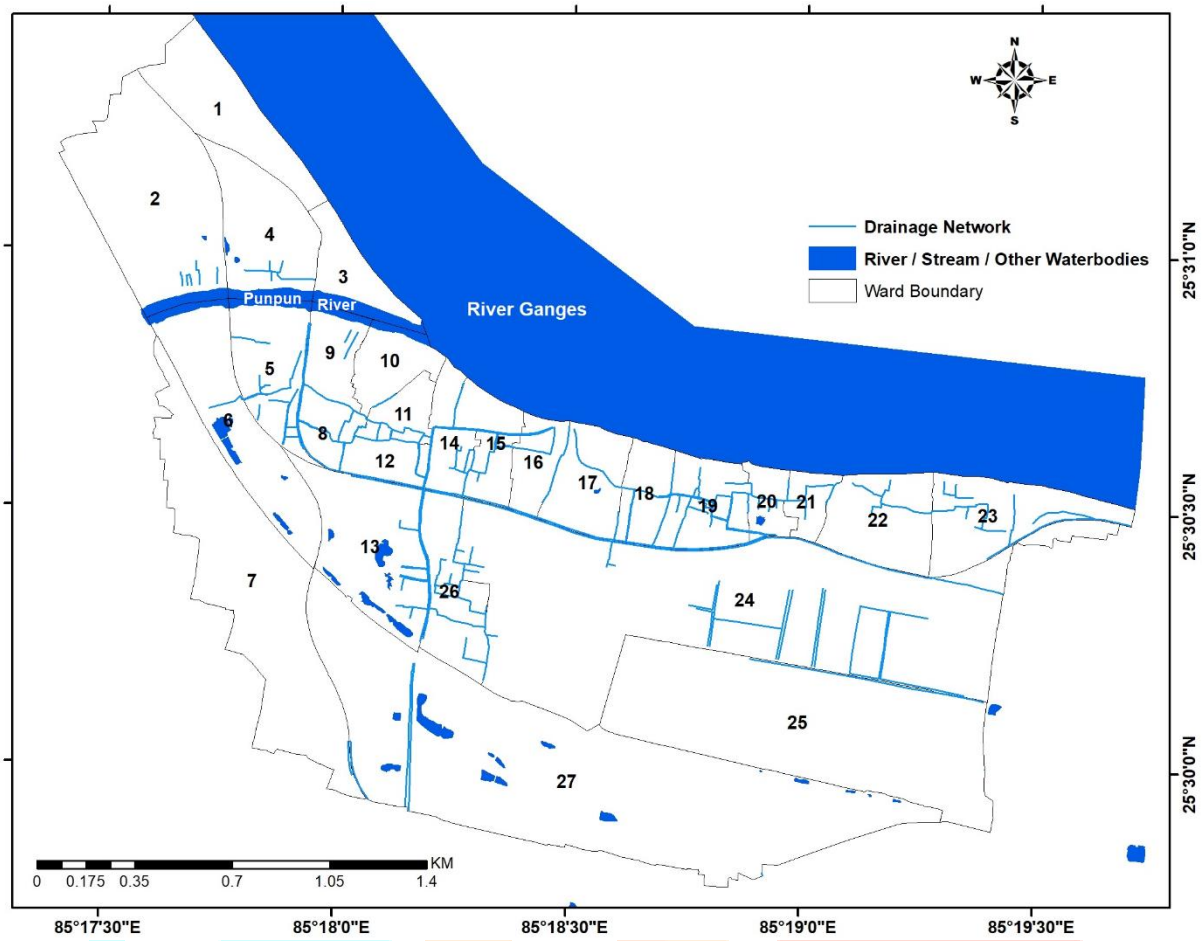

Figure 2: Distribution of drainage network in Fathua municipality

Road network

Due to its close proximity to Patna, the state capital, Fatuha serves as a major centre for the supply of products into and out of Patna. NH-30 A links Patna to the Nalanda district and further through Fatuha. Likewise, NH 30 links Patna to northeastern India, Fatuha serves as Patna's eastern entrance. By way of the Kachchi Dargah-Rustampur connection, Fatuha is connected to the trans-Ganges neighbourhood of Vaishali. The city does not have a substantial hierarchy of roadways. When it comes to elements like traffic management and road geometry, the entire road network system is lacking. The main forms of urban transportation are auto-rickshaws and minibuses, with little to no assistance from a public transportation system. Figure 4 portrays the geographical variation of road network in the study area. Based on the road density the study area is divided into 5 categories, namely (i) <9.5 per sq km, (ii) 9.5 – 20 per sq km, (iii) 21 – 31 per sq km, (iv) 32 – 45 per sq km, and (v) > 46 sq km. The highest road density (>46 per sq km) is calculated of ward no. 5, 8, 9, 11, 12, 14 19 and 23. The lowest road density (<9.5 per sq km) is calculated of ward no. 2, 7, 25 and 27 in the study area. Due to the poor state of the public transportation system, the absence of a mass transit system, and the comparatively simple availability of loans, it has been noticed that the rise of personalised vehicles, such as two-wheelers and cars, is quite rapid. The predominance of low-capacity modes like bicycles and cycle-rickshaws in the metropolis is distorting the modal mix and making travel dangerous and expensive.

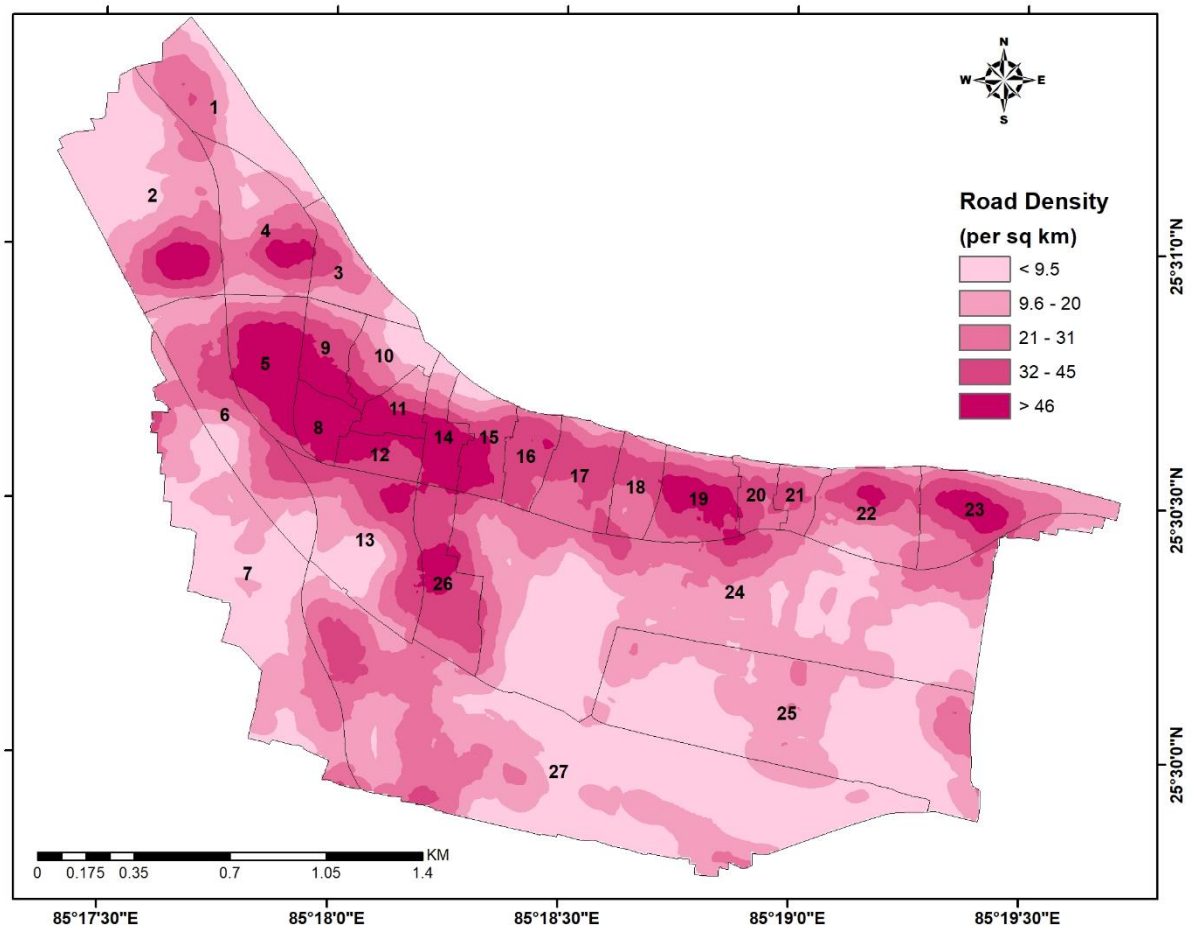

Figure 3: Road density map of Fathua municipality

Urban Housing

The Fathua Municipality, whose urban population is expected to treble between 2011 and 2031, depends heavily on housing to facilitate urban development. Fatuha is a significant rural market that serves the requirements of several communities that produce various agricultural and rural goods including handicrafts. In its industrial sector, Fatuha—a significant Bihar industrial hub—manufactures agricultural tractors, scooters, and other goods. The industrial sector is growing again, and Bharat Petroleum's LPG bottling facility is currently located in Fatuha. Most of the urban housing is observed in northern and central part of the study area (Figure 4).

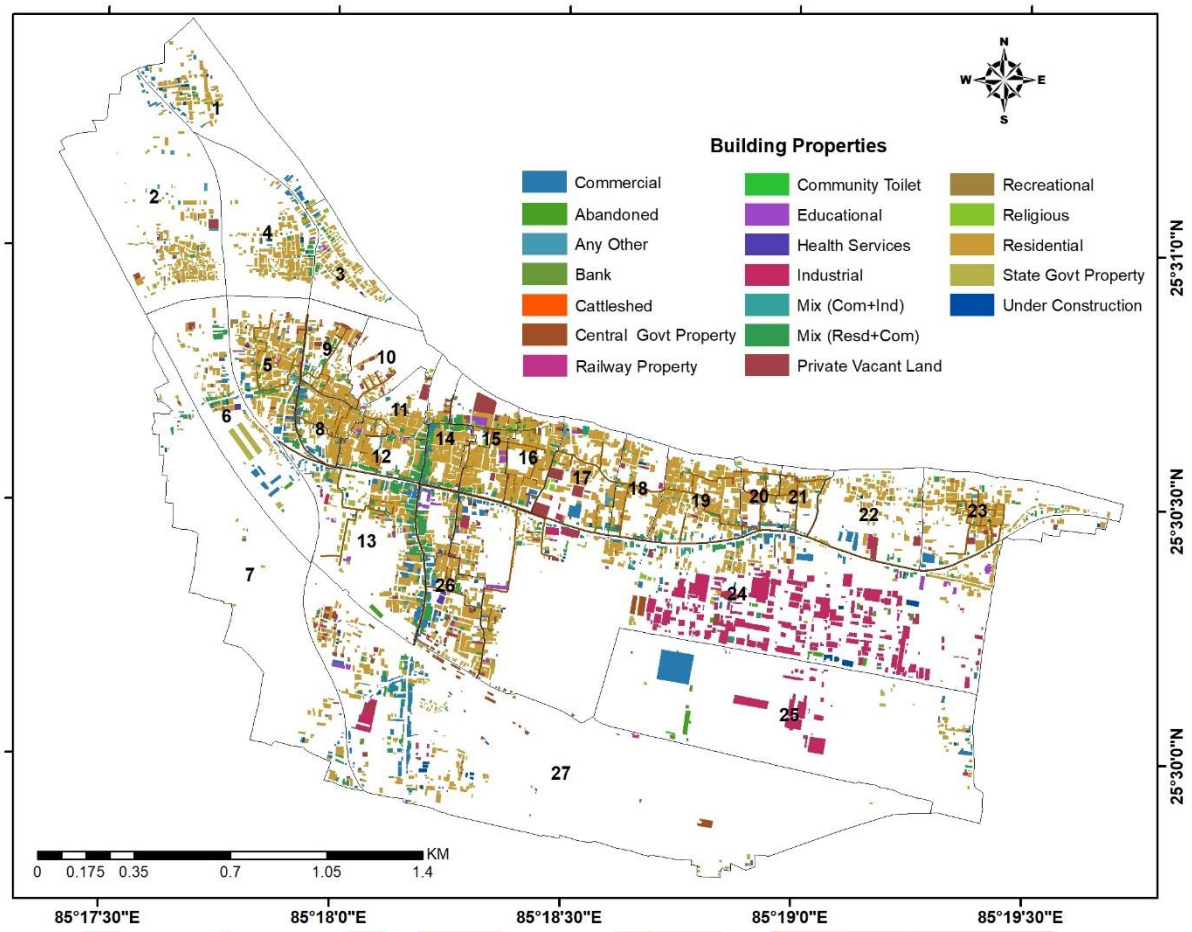

Figure 4: Geographical distribution of urban housing pattern of Fathua municipality

It has been determined that there is very limited room for upgrading or rebuilding in older regions by taking a look at the current places with crowded nature of housing in the city. Housing will be made available primarily in new locations to provide the necessary demand. According to the existing geographical distribution of types of housing in the research region, one- and two-room dwelling units will be the most common forms of shelter needed in the foreseeable future. For the purpose of providing housing stock and delivering serviced land, it is suggested to include the private sector, government organisations, cooperative organisations, etc.

Water Supply network

The water supply for Fathua City has been provided through a decentralised system using one or more tube wells with clear command boundaries. The current distribution system is extremely dated, has significant leaks, and is heavily incrusted, which severely reduces it carrying capacity and contributes to water pollution. Figure 6 illustrates the density map of water supply network distribution in Fathua municipality. Results shows the maximum density of water supply network distribution is estimated from ward no. 5, 8, 11, 12, 14, 15, 18, 19 and 26. The least density of water supply network distribution is estimated for ward no. 1, 2, 7, 25 and 27.

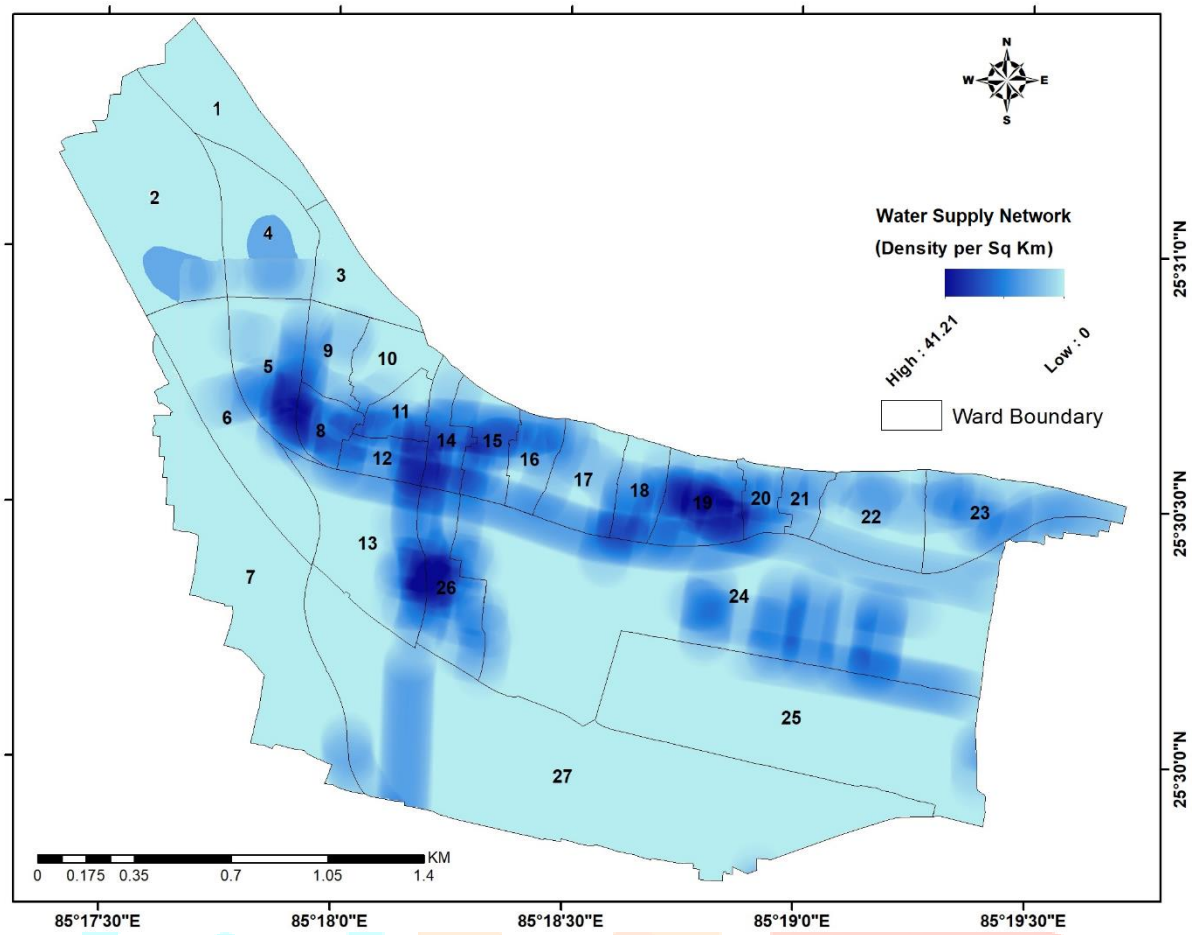

Figure 5: Density map of water supply network distribution of Fathua municipality

A number of tube wells have been grouped together and put into operation as the water distribution network as needed. As a result, although some locations have an abundance of water supplies, others severely lack it. This is a result of water being distributed unevenly. It is crucial to analyse pipeline networks on a zone-by-zone basis and adhere to the best network through route rationalisation in order to ensure that water is distributed equally throughout all locations.

Power supply network

The state power supply system or the Patna Metropolition area include the urban power supply system. Substation location in cities presents challenges because to the constructed landscape and individual ownership on earth. Since electricity is the most accessible and widely used energy source in contemporary cities, it has grown to be a crucial energy source for urban growth (Du et al., 2021). The rate at which urbanization is increasing and family living standards are rising will result in a higher environmental concern as households use more electricity for everyday transportation, heating, cooling, cooking, lighting, and production. Figure 6 shows the spatial distribution of power supply network density of Fathua municipality. The maximum density is observed in ward no. 24 and across the border of ward no. 16, 17, 18, 19, 20 and 21. The low density of power supply network is observed in ward no 1, 2, 3, 4, and 27. The medium density of power supply network is observed in ward no. 5, 6, 8, 9 and 10 within the municipal area.

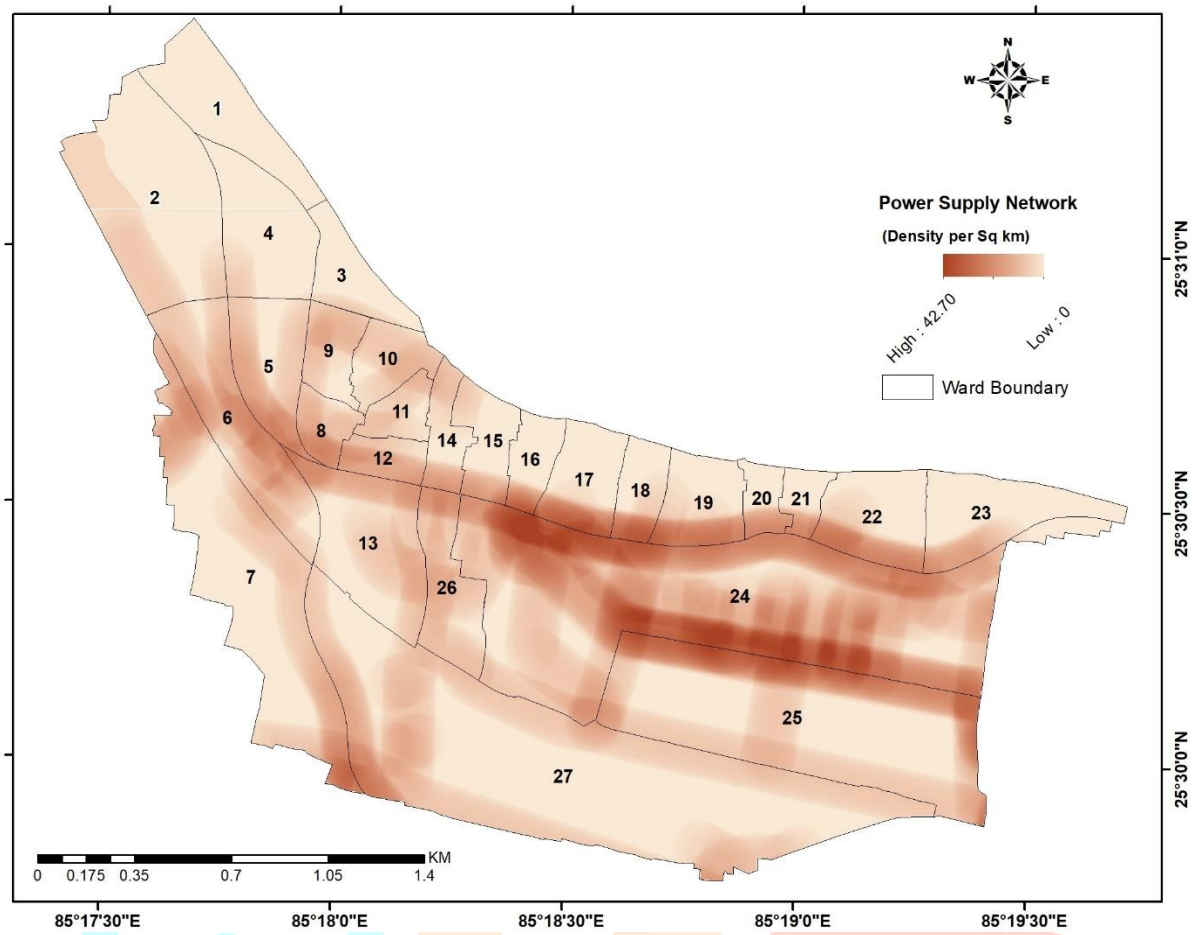

Figure 6: Distribution of power supply network density in Fathua municipality

Summary

Infrastructure refers to the essential services and facilities required for an economy to operate as well as the fundamental physical and organisational structures required for the operation of a society (Weijnen and Correljé, 2021). The most effective planning was done in the present research to acquire both visual and comprehensive information and network analysis techniques for location management decisions and geographic data inquiry. In the study area, it is observed that most of the infrastructure development is taking place in north and central region. Infrastructure development is much more needed in south and eastern part of the Fathua Municipality. Making judgements based on the system's total data has the potential to be advantageous in promoting economic growth, improving city planning, and preserving significant structures and cultural and historical monuments (Bibri et al., 2020). Additionally, it seems that GIS design and improved decision-making save users' time.

Implementing town-wise planning decisions might be greatly aided by the GIS database's usability. Future projections of rising electricity consumption, the need to enhance the quality and consistency of energy delivered to consumers, and the rapid advancement of renewable energy sources will render the present-day distribution area grid infrastructure inadequate. It will be crucial to fully modernize and expand it, particularly in relation to the 11 kV distribution network and in significant metropolitan agglomerations.

This study uses the GIS as an "intelligent" database. Using geographic information systems (GIS), a small region is created where a variety of digital data, including as photos, maps, papers, and images, may be kept that are pertinent to the Fathua Town area. Decisions for subsequent scheduling, design, and site management will be based on these assessments. There is an infinite array of questions, each one specific to a potential user. Local decision-makers will have the chance to create a comprehensive and comprehensive town planning if the plan and its execution are effective.

Acknowledgement
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