FACILITY BASED RURAL ROAD NETWORK PLANNING USING SPATIAL TECHNIQUES

Submitted in partial fulfillment of the requirements

for the award of the degree of

Doctor of Philosophy

By

Anil Modinpuroju

701302

Department of Civil Engineering

NATIONAL INSTITUTE OF TECHNOLOGY

WARANGAL

JULY 2019

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Approval Sheet

This Thesis entitled **“Facility Based Rural Road Network Planning Using Spatial Techniques”** by **Mr. Anil Modinpuroju** is approved for the degree of **Doctor of Philosophy**.

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Declaration

This is to certify that the work presented in the thesis entitled **Facility Based Rural Road Network Planning Using Spatial Techniques** is a bonafide work done by me under the supervision of **Prof. C.S.R.K Prasad** and was not submitted elsewhere for the award of any degree.

I declare that this written submission represents my ideas in my own words and where others' ideas or words have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea / data / fact / source in my submission. I understand that any violation of the above will be a cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

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(Signature)

Anil Modinpuroju

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NATIONAL INSTITUTE OF TECHNOLOGY

WARANGAL

Certificate

This is to certify that the thesis entitled **"Facility Based Rural Road Network Planning Using Spatial Techniques"** submitted by **Mr. Anil Modinpuroju** to the National Institute of Technology, Warangal, for the award of the degree of **Doctor of Philosophy in Civil Engineering** is a bonafide research work carried out by him under our supervision and guidance. The results contained in this thesis have not been submitted in part or full to any other University or Institute for award of any degree or diploma.

(Prof. C. S. R. K. Prasad)
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Warangal,

Date:

Dedicated to

My
Beloved Family
&
Gurus

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Anil Modinpuroju

Date:

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ABSTRACT

Provision of good rural roads to meet the public facilities changes the characteristics of rural transport. Efficient rural transportation depends largely on a well-knit road network to provide accessibility and mobility in rural areas. Rural roads are primary infrastructure which provide essential access to rural population to various social facilities such as education, health, transportation and market facilities. Transportation planning in rural areas is highly complicated because of the multiple activities having non-specific interaction between any two places. Various models for planning of rural road network were developed by different research organizations, educational institutions, and consultants but in actual practice, they have not been of much help to implementing agencies (shrestha 2013). There is a need for the consolidation of the existing rural road network for maintenance and connectivity to the local community and enable economical transportation of goods and services to provide better livelihood opportunities as part of poverty reduction strategy.

One of the primary constraints in the development of rural infrastructure is the lack of sufficient funds in developing countries. Apart from the limited resources to build rural infrastructures (roads, water supply, electricity, telecommunication network) and public facilities, the lack of proper planning methodologies for development, improvement, and management of rural infrastructure is also a significant problem. Optimal use of available funds is a necessity and may help to develop and improve the present situation. Populations covered by a road link (Kumar and Kumar, 1999) can be taken as significant indicator to be considered to take into account the socio-economic benefits from the rural road links. The

other factors can be costs (construction costs and travel costs). However, these factors cannot be assessed precisely for rural areas. Hence, costs can be considered indirectly taking distances (construction cost) and the person-km (travel costs) (Kumar and Tilloston, 1985; Makarchi and Tilloston, 1991; Singh, 2010).

This study envisages consolidation of the existing Rural Road Network to improve its overall efficiency as a provider of transportation services for people, goods and services. The proposed methodology in this study, enables to determine rural hubs in the rural areas based on the facility index of the settlements. The Village Facility Index (VFI) is calculated by considering the desirable coverage distance. Spatial analysis is carried out in the study area to identify the Desirable Coverage Distance of the Facility (DCDF). VFI is the summation of all facility indices such as Educational Facility Index (EFI), Medical Facility Index (MFI), Transportation and Communication Facility Index (T&CFI) and Economic Activity Facility Index (EAFI).

The rural road network is generated by connecting the rural hubs by minimum travel time path in Geographical Information System (GIS). In the present study, travel time was measured from the field by travelling along the road using design vehicle. In a place where the terrain is not flat and the level difference between the two origin-destination points is very high, travel time was considered in both directions. In this study, since the terrain is plain and traffic volumes in both directions are more or less equal, the travel time in both direction is assumed to be same. The Minimum Spanning Tree (MST) of network is generated from the existing rural road network. MST represents the minimum connection level necessary for the rural accessibility of a specified coverage distance. In this study, MST of network is considered as the optimal road network of the study area.

Fund available for rural road construction/upgrade is usually a constraint in developing countries. Hence, the available resources should be effectively used. For this, a prioritisation method is necessary. Based on a realistic and practical criterion, the rural road links in the network are to be prioritised. The study explored the different rural road network models for prioritization of links for new construction and upgradation works. In this study, planning for prioritization of links is achieved by considering two parameters i.e. population and vulnerability of link**.** The model allows investigating the public resource allocation to attain minimum total cost with an investment budget constraint, intended to design the infrastructure by keeping total transportation costs to a minimum.

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LIST OF ABBREVIATIONS

ANM	-	Auxiliary Nurse Midwifery
CHC	-	Community Health Centre
DCDF	-	Desirable Coverage Distance to Facility
GIS	-	Geographic Information System
GPS	-	Global Positioning System
IRC	-	Indian Road congress
MORD	-	Ministry of Rural Development
MST	-	Minimum Spanning Tree
OMMAS	-	Online Management, Monitoring and Accounting System
PCI	-	Pavement Condition Index
PHC	-	Primary Healthcare
PMGSY	-	Pradhan Mantri Gram Sadak Yojna
RRIS	-	Rural Road Information System
RRNM	-	Rural Road Network Model
VFI	-	Village Facility Index
WIM	-	Weighted Index Method

Chapter 1

INTRODUCTION

1.1 General

The growth and development of all major sectors of the economy including health, education, and economic activity centers depend on availability of transport facility. In the sphere of integrated rural development, transportation plays a significant role. Scwatt (1987) opined that rural transportation network will give shape to the living environment of villagers and roads of rural transportation are connecting elements in the society. Rural roads have a very significant impact on socio-economic development of people who reside in rural areas. Rural roads are the lifeline of India with 68.8% of the population living in rural areas, according to 2011 census. Proper infrastructure facility planning helps in mitigation of poverty, the creation of more employment opportunities and improvement in the quality of living standard of the people. The primary objective of rural roads is to open up parcels of land, to collect the individual transport requirements and to connect them to the growth points.

Rural roads are primary infrastructure which provide essential access to rural population to various social facilities such as education, health, transportation and market facilities. An overall economic development of the country level is achieved if adequate transportation facilities are made available to all the villagers to have a safe, convenient, reliable and economic access from villages to market centers and district headquarter to bring them into the mainstream of economic and social development. In order to achieve measurable benefits from rural areas, it is necessary to provide a level of accessibility, which ensures connectivity of every villages to school, hospitals, post- office, banks and other amenities with all-weather roads. The existing road networks in about 35% of the rural areas of India are still earth tracks and footpaths (Kumar et al. 2011).

1.2 Problems in Rural Development and Importance of Rural Transportation

Transportation planning in rural areas is highly complicated because of the multiple activities having non-specific interaction between any two places. The inconsistency in demand and supply interaction, suppression of latent demand by inadequate supply generate a wide gap in the development of interactive capabilities among potential demand-based villages.

Konstantinous et al. (1987) explained the adequate provision of physical and social infrastructures will enhance the introduction and adoption of innovations offered by institutional infrastructure, which is a significant term used for judging the development level of a country. Gramlich (1994) gives three different versions of the classification of infrastructures. From financial viewpoint, the first version consists of large capital-intensive natural monopolies such as highways, other transportation facilities, and communications systems, water and sewer lines. The second version focusses on ownership and is defined as the real capital stock owned by the public sector. The third version includes successive human capital formed by investment in research and development. Places of residence, places of work and production must be accessible by vehicles at any time for economic, social and cultural reasons (Schatt, 1987).

The development in rural areas is related to accessibility and affordability of services to rural communities. Rural road construction is an intervention for rising living standards in deprived rural areas (Gannon and Liu, 1997). Due to the lack of transport accessibility, essential goods and services do not reach the majority of the rural population.

With hilly and mountainous topography, better roads and optimal facility locations reduce isolation and economic vulnerability of rural residents. Enhancement of transport accessibility to settlements and various public facilities is vital to the economic survival and welfare of rural communities.

The role of rural roads is significant since well-connected rural roads integrate different social, cultural and ethnic groups besides providing accessibility between villages, marketplaces, processing centers, health care units and so on. These roads ensure better farm gate prices for the agricultural produce, provide access to agricultural extension services and modern technology leading to the adoption of scientific farming practice with timely availability of current agricultural inputs. These roads facilitate all-round development of rural areas and reduce their migration to urban areas for jobs (Ramesh C.R, 1998).

The social and economic benefits derived from rural roads are many. Research on the impact of improved accessibility has been carried out, and there are many examples, where it has been shown that the average domestic product, literacy, and employment opportunities had increased significantly to provide higher standards of living (Mahendhru et al. 1998). World Bank has also attempted an economic appraisal of rural road projects for investment priorities. In this context, National Transport Policy committee (NTPC, 1980) has indicated that roads provide six times more employment potential than railways.

1.3 Status of Indian Road Network

The country has approximately a total road network length of 54.73 lakh kilometer as on March 2015. The division of the entire road network is as given in Figure 1.1.

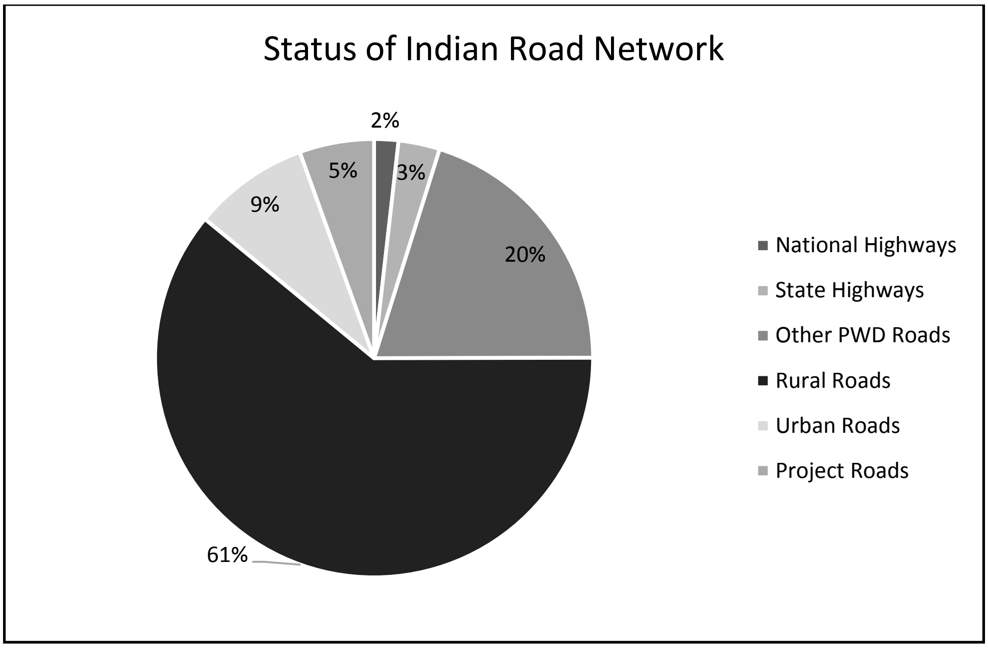

Figure 1.1: Present scenario of road network in India

Rural roads are a significant part of the Indian road network. Roads in rural area cover 3.3 million kilometers and these include Panchayat raj roads, Pradhan Mantri Gram Sadak Yojna (PMGSY) and Jawhar Rozara Yojan (JRY) roads and the status of rural roads is shown in Figure 1.2. The planning, execution, and maintenance of these rural roads presently vested with Zilla Parishads

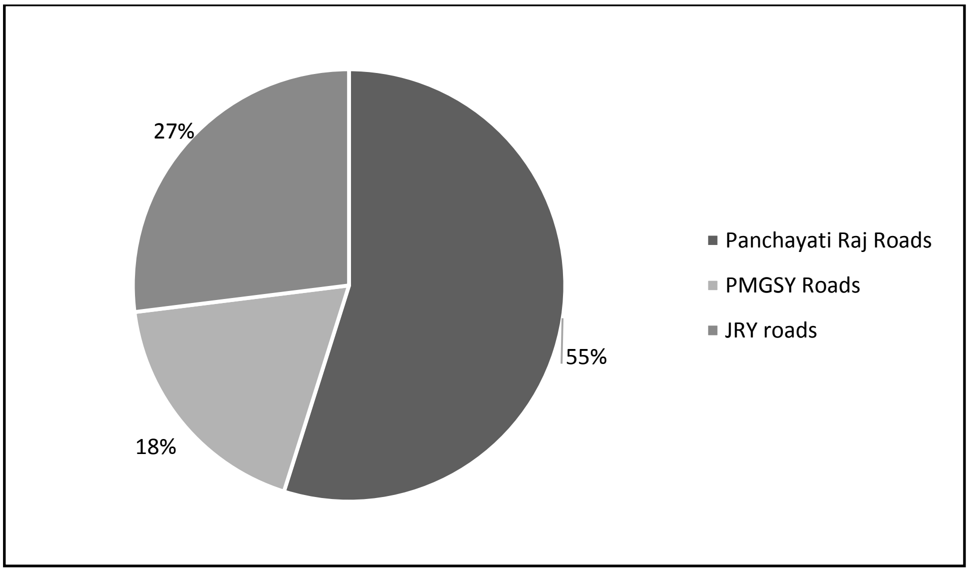

Figure 1.2: Rural road status in India as on March 2015

1.4 Major Rural Road Development Programs in India

The rural road development plans in India were taken up in the following phases:

- Underlining the need for higher road growth in the rural sector, the Indian Roads congress (IRC) made its efforts to set up a committee in 1958 to recommend measures for rural road maintenance.
- Ministry of Transport set-up a committee that envisaged the requirement of rural roads as 5, 54, 000km in its report and recommended a high-level rural board for each state (Rural roads, 1968).
- In 1969, the rural road committee prepared a compressive report on planning, specifications, financing, construction, and maintenance of rural roads.
- National rural employment program was introduced in 1980 replacing the earlier "Food for Work" scheme. Rural road construction was an essential part of this program.
- Road development plan of 1981-2001 is a comprehensive plan covering design and construction standards, maintenance, environment, finance, resource management, human resources management, organizational matters, construction agencies, R&D, social and economic development. This plan envisages all-weather road connection to all villages by the year 2001.

1.4.1 National Transport Policy Committee (1980)

This committee made the following recommendations:

- Network approach has to be applied to rural road planning. District wise master plans for rural roads are to be prepared in all the states.
- Rural road programs are to be integrated with the rural development program.
- Additional sources of finance are to be supplemented in addition to state plan resources.

- A provincial road commission should be set up at the Centre for coordinating various rural road programs at the national level.

1.4.2 Study on Indian Roads Planning by Planning Commission (1985)

The planning commission in the past has requested the states to prepare the master plans on rural roads to facilitate the execution of five-year and annual plans. It is to avoid ad-hoc approach. The planning commission set up a committee to study the integration of different programs for construction of rural roads and the committee submitted its report with the following observations and recommendations:

- There is absence of uniform criteria for selection of road works, planning of ways, and fixation of alignments.
- Construction of rural roads by multiple agencies has to be stopped, and the work has to be handled by a unified and technically competent engineering organization.
- The monitoring of rural roads and villages connectivity should be strengthen.
- States should draw master plans for rural roads, and these are to be updated periodically to cover the needs of new growth centers.

1.4.3 Pradhan Mantri Gram Sadak Yojna (2000)

In the year 2000, Government of India (GOI) launched a nationwide program, the Pradhan Mantri Gram Sadak Yojna (PMGSY), under the Ministry of Rural Development (MORD). The primary objective of PMGSY-I is to provide connectivity by all-weather roads to unconnected habitations. In the rural areas it is to be done in such a way that dwellings with a population of 1000 and above are covered in three years (2000–2003) and all unconnected habitations with a population of 500 and over by the end of the Tenth Plan Period (2007). In respect of the Hill States and the desert areas as well as tribal regions, the objective would be to connect habitations with a population of 250 and above in the same manner as discussed above. It is estimated that the total investment required to meet the targets by 2007 is Rs 60,000 crores. The National Rural Road Development Agency (NRRDA) has been made responsible for monitoring the program, execution, and implementation. The program is implemented through the state level agencies by preparing the detailed District Rural Road Plans (DRRP) and Core Network (CN).

In May 2013, with the aim to consolidate the entire rural road network, PMGSY-II was launched for upgrading existing selected Through Routes and Main Rural Links. Selection of roads was based on their economic potential and their role in facilitating the growth of rural market centres and rural hubs. The growth center and hub would provide market facilities, health facilities, banking facilities and other infrastructural facilities enabling the creation of new employment and opportunities. The Growth Centre is defined as an area of a relatively centralized population providing rural socio-economic services, not for a small space but a large area within a radius of several kilometers. The objective of PMGSY-II scheme in the 12th Five Year Plan period is to attain a target length of at about 50,000 Km. The overall targets achieved by this scheme are presented in Table 1.1.

Table 1.1: Targets and achievements of PMGSY

<table>
<tr><th colspan="4">Overall Physical Targets and Achievements of PMGSY (up to Dec. 2017)</th></tr>
<tr><th colspan="4">New connectivity to eligible Unconnected habitations</th></tr>
<tr><th>Total eligible habitations as per core network</th><th>Nos. of Habitations for which Projects sanctioned</th><th>No. of eligible habitations connected</th><th>Total Habitations connected</th></tr>
<tr><td rowspan="2">1,78,184</td><td rowspan="2">1,64,547</td><td>1,30,974 (Connected under PMGSY)</td><td rowspan="2">1,45,594 (81.7% of eligible habitations)</td></tr>
<tr><td>14,620 (Connected under State Schemes)</td></tr>
<tr><td></td><td>Length sanctioned- 4,11,617 kms</td><td>Length completed- 3,38,024 Of cleared (82.12%)</td><td></td></tr>
<tr><th colspan="4">Upgradation of Rural Roads under PMGSY-I (length in km)</th></tr>
<tr><th>Total Target length</th><th>Length sanctioned</th><th>Length completed</th><th>Balance yet to be completed out of sanction</th></tr>
<tr><td>2,24,906</td><td>1,99,755</td><td>1, 75,903 (78%)</td><td>23,852 (12%)</td></tr>
<tr><th colspan="4">Upgradation of Rural Roads under PMGSY-II (length in km)</th></tr>
<tr><td>Total Target length</td><th>Length sanctioned</th><th>Length completed</th><th>Balance yet to be completed out of sanction</th></tr>
<tr><td>50,000</td><td>29,148</td><td>12,984</td><td>16,164</td></tr>
<tr><th colspan="4">Total Length completed- 5,26,911 kms, Total length sanctioned 6,40,520 kms (Both PMGSY-I & II)</th></tr>
</table>

(Source: pmgsy.nic.in)

1.5 Rural Road Information System (RRIS)

In general, RRIS is developed by integrating the spatial and attribute data of rural roads. GIS has been used as a useful tool for village and road information system, which will help the planners and administrators to identify the problems associated with rural road development activities, location, and provision of appropriate facilities, monitoring and maintenance management of the assets in rural areas.

RRIS will help planners for planning and implementing road development plans in rural areas. It comprises all the information related to the facilities, infrastructure, population, type of pavement, traffic volume, Pavement Condition Index (PCI), etc. With the help of conventional methods, the database and maps required for any research and development projects are brought to a common platform, but it needs too much time and labour. To overcome such difficulty, GIS is a helping tool to generate such comprehensive maps and also in a precise manner. With the help of GIS, information can be stored, updated, manipulated and retrieved whenever required (Getachew, 2012).

1.6 Motivation for the Research Study

Various models for planning of rural road network were developed by different research organizations, educational institutions, and consultants but in actual practice, they have not been of much help to implementing agencies (Shrestha 2013). Issues such as a comprehensive database of the area, aspiration of local people and their access needs, land acquisition issues, alignment and construction cost of road links, upgradation of existing fair weather roads to all weather standard, etc., are not adequately addressed in these models. The overall practical utility of these models is, therefore, limited. There is a need for the consolidation of the existing rural road network for maintenance and connectivity to the local community and enable economical transportation of goods and services to provide better livelihood opportunities as part of poverty reduction strategy. Considering these requirements, different methodologies have been suggested.

One of the primary constraints in the development of rural infrastructure is the lack of sufficient funds in developing countries. Apart from the limited resources to build rural infrastructures (roads, water supply, electricity, telecommunication network) and public facilities, the lack of proper planning methodologies for development, improvement, and management of rural infrastructure is also a significant problem. Optimal use of available funds is a necessity and may help to develop and improve the present situation.

Research on the planning of rural infrastructure in a comprehensive and integrated manner is a dire need for rural development. However, the primary lifeline infrastructure in rural areas of developing countries is rural roads and these are vital for the development and operations of other hard and soft infrastructure. In this way, the topic of this work envisaged a planning methodology for rural road networks that considers the public facilities location and the rural road network simultaneously.

1.7 Objectives of the Study

Many works were extensively studied for the development of infrastructure in the past. They were reviewed independently without consideration of other related factors. Therefore, it is essential to investigate rural road network models where rural road networks are optimally designed considering existing and new public facility locations to achieve minimum cost comprising construction and operation costs. The rural infrastructure planning methodology was developed based on the rural road networks.

The primary objective of this work is to investigate a rural road planning methodology considering connectivity of roads in rural areas. Based on this objective, the following specific objectives are obtained:

- To develop a methodology to identify rural hubs in rural areas.

- To develop a planning methodology to define an optimal rural road network.
- To develop models that optimize rural road networks for new connection and upgradation.

1.8 Thesis Outline

This report consists of seven chapters. A brief introduction and general description of the studies made in this thesis is presented in Chapter 1. A detailed presentation about rural areas, the role of geospatial technologies in rural development, motivation to carry out the work and objectives of the research work are also given in this chapter. Based on the proposed objectives, literature review was carried out to detail the research being carried out worldwide and this constitute chapter 2. Existing rural road models were reviewed from basic literature concepts of rural road planning. This idea was used to develop the proposed rural road network model. Based on the literature review, a methodology has been prepared to carry out the proposed work. The third chapter highlights the overall methodology adopted to achieve the intended objectives of the research work. Study area and database preparation are also presented in this chapter. Chapter 4 explains identification of rural hubs by estimating the village facility index. Definition of optimal rural road network using minimum travel path analysis and GIS was presented in chapter 5. The network analysis is carried out in this chapter and similarly this analysis is projected to district level. Rural road optimisation models are presented in Chapter 6. The first model Rural Road Network Model-1 (RRNM-1) is a general-purpose rural road model for new connections. The second Rural Road Network Model-2 (RRNM-2) is introduced for an upgradation of the rural road network in plain areas. Prioritisation procedures are introduced for the selection of rural roads links for intervention at different budget levels. Main conclusions are drawn in chapter 7, after summarising the main findings of each chapter. Moreover, limitations and future research directions are also presented.

Chapter 2

LITERATURE REVIEW

2.1 General

Many of the developing countries have undertaken plans designed to upgrade transport facilities in rural areas to improve social and economic life. To achieve the aim of increasing the reliance of the rural population on agriculture and increased access to essential services, the level of rural transportation has to be improved.

Policymakers have increasingly realized the advantage of rural roads in developing countries. For systematic development of rural roads, some rural road planning models are used. There is a rich body of literature on transport network models, focusing mainly on urban problems (Shrestha 2013). Hence, there are many advanced models for the development and improvement of urban transport networks. Unlike urban transportation, rural transportation mainly deals with providing connectivity/accessibility to local settlements. As it is still in developing phase, very few studies deal with the subject of rural road network planning and development. Prioritization is the most straightforward approach in rural road network planning. Road links are prioritized based on the population that benefit as well as socio-economic benefits from the link. Various research works carried out on the preparation of rural road network, the design of optimal rural road network and application of advanced geospatial technologies in the rural development are described briefly in the following sections.

2.2 Review on Rural Road Planning Methods

In this section, some existing methodologies for rural road planning and development are presented. The review of the current methods will give some background to identify lacunae in existing literature. These issues are incorporated in the further development of a methodology that will be more sensible and useful in specific contexts.

There are many methods to rural road planning. In India, rural road planning at the national level was towards improving existing fair-weather road to all-weather standards and to provide adequate cross drainage structures, wherever these are missing (The Road Development Plan Vision: 2021 (IRC 2001)).

2.2.1 Priority Ranking (PR)

Satsangi et al. (1984, 1986) developed a transportation priority indices to villages in the study area. Socio-economic characteristics and distance of separation were considered as inputs and attempted regression analysis with transportation priority index as the dependent variable and identified length and density of roads as influencing factors.

Srinivasan et al. (1987) developed a network-planning model in three stages: Node choice, link choice, and network optimization. Transport priority index (TPI) was designed and used for node choice. For link choice, various indices of network analysis were considered. Network optimization was carried out with Village affinity index (VAI) based on gravity concept and population and the distance being considered as inputs.

Konstatinous et al. (1987) examined the relationship between the location of health centers and roadway network in rural areas of Greece. Connectivity indices like alpha, beta and Gama were identified and accessibility values were recommended. These indices measures the connectivity level of the network. These accessibility values indicate the number of physical facilities required in the system.

Kevin (1988) developed an approach of priority system, where direct access locations were connected to the surrounding arterial system, and the methodology recommended was the identification of service centers by considering geographical area and employment activity.

2.2.2 Benefit/Cost Analysis (BCA)

UNCHS (1985) suggested a simple evaluation criterion for network generation. A graph-theoretic measure of connectivity and spatial accessibility was considered as inputs in a network for evaluation. The procedure was aimed to identify the most accessible routes between settlements. The approach illustrates the policy of reducing road-building cost by providing low-quality roads, while enhancing accessibility levels for rural communities based on the benefit from the construction of the rural road.

Shrestha (2003) prioritized the rural roads in Nepal based on economic benefits. The prioritization of roads in the developed area was based on the Economic Net Present Value (ENPV), an Economic Internal Rate of Return (EIRR), and the Benefit-Cost (B/C) ratio. This methodology was biased to choose links, which connect heavily populated and economic centers.

2.2.3 Costs

Kumar and Tillotson (1987) suggested a computer-based planning model for rural roads. The optimum rural road network was generated by connecting each village to nearby main roads or market centers by providing an all-weather road with least cost.

Makarachi et al. (1991) suggested a methodology for identification of link choice by considering minimization of travel and construction cost. The method was initiated with the development of shortest trees to suggest a minimum construction cost based network. In this network, each link was scanned with user cost as a function of population and distance parameters. A link choice was identified, which minimizes the travel cost. The outcome of this methodology suggests a network, which serves maximum population with consideration of construction cost.

Kumar and Kumar (1999) demonstrated a user-friendly computer-based model for rural road network planning. The model provides an all-weather road connection from each village to nearby market centers and education centers at least cost.

2.2.4 Intensity of Interaction

Mahendru et al. (1988) developed a hierarchical system and a centrally located settlement was identified as the central place of one kind, and it was supposed to serve the surrounding settlements for their missing functions. To develop the full network, one of the criteria could be minimization of total link length or minimization of entire route length.

Shrestha and Routery (2002) used the gravity model for the planning of rural roads. Hierarchy of settlements was estimated using the interaction between the settlements. The distance between centers plays a vital role in generating trips following a distance decay function. The force of interaction between two settlements can be obtained by gravity model.

Mishra (2008) proposed inter-settlement interaction and functional accessibility approach for rural road network planning. In the proposed model, prioritization and ranking of settlements for the rural road connectivity was based on their population size and socio-economic status.

2.2.5 Facility Based Approach

Kumar and Jain (1997) presented the facility based rural road network-planning model based on a survey conducted in 35 villages of Ghaziabad district in Uttar Pradesh state. They observed that 92.79% of trips either terminate at market or at an education Centre. They studied and found that, if the network is planned with the objective to connect the village to education and market center, it will possibly be the most efficient network. This model was based upon regression equation, where distance is an independent variable and education level is the dependent variable. It was observed that as the distance from the education center increases, then education level starts dropping.

Gosh et al. (2002) developed a spatial decision support system for planning health and education infrastructure for Ranchi district. Education and medical facilities indices were calculated in this study. The weights for the facilities are calculated using principal component analysis and the areas to be concentrated have been known for proper planning of infrastructure.

Gupta (2007) proposed a geo-statistical model for assessing development at micro level. Developed a computer program in Arc Macro Language (AML) to find out the median population threshold, facility composite index and correlation matrix and village development index by calculating weights for various facilities using Weighted Index Method (WIM).

Garg (2008) explained the importance of GIS in infrastructure planning. The rural areas have been prioritized using Weighted Index Method (WIM). Spatial analysis was carried out to understand the concentration of overall development. Various indices were calculated and the clustering of villages was carried out based on the calculated overall index. He studied the importance of prioritization of villages and proposed clustering of villages based on Providing Urban Amenities in Rural Areas (PURA) concept.

Aditya and Acharya (2011) attempted to examine and analyses the impact of spatial disparities in infrastructural facilities for 16 states in India. In this study, Infrastructure Development Index (IDI) was calculated by considering various infrastructural services. The effect of these parameters on economic growth is studied using correlation matrix and path regression analysis and they concluded that more infrastructural facilities should be provided at state level in order to increase the state domestic product and reduce the unemployment and poverty level of people.

Chakraborty et al. (2012) identified the relationship between infrastructure, employment, opportunities and the level of living standards in rural India. They identified some core infrastructural facilities, which are critical for the development of rural economy and evaluated the Village Facility Index (VFI) of each village and differentiated the villages based upon VFI value. They analysed the expenditure pattern of household among different categories of villages. The communities were then categorized based upon on the index, and related socio-economic profiles for each class of villages to get an idea of the overall well-being of rural folk in India.

Navatha et al. (2015) determined facility index for Geesugonda mandal in Warangal district of Telangana state. This facility index method was used as the rank group for area-based infrastructure availability, where many parameters were taken into consideration. In this study, facility index was calculated by weighted index method and entropy method. Based upon data obtained, the spatial variation of ranks was studied, and a group of three or four villages was combined to form a cluster based on Providing Urban Amenities in Rural Areas (PURA) concept.

Kanuganti et al. (2017) suggested a need-based approach for rural road network planning. In this study the facilities considered as basic needs consist of providing accessibility to primary school, middle school, high school, Community Health Center (CHC) and local government head quarter. Threshold distance for each facility was considered for planning of network. Prioritization technique has also been suggested for constructing need-based routes to improve rural accessibility to basic facilities.

2.3 Review on Rural Road Network Generation

Swaminathan et al. (1982) developed a scientific and straightforward approach for the development of road network. Minimum spanning tree concept was used for connecting the settlements to existing nearby roads or the nearest market. Principles of the graph theory and specific weights were used in determining the optimal linkage.

Mahendru et al. (1982) introduced functional utility concept for identification and classification of rural roads. The suitable weight scale was developed depending upon the frequency of various functions. Weight scale thus produced can be used to assess functional utility score for each settlement. Every settlement of lower order has to depend upon the nearest higher order settlement. After taking up the spatial planning of settlement and hierarchies needed, a linkage pattern was developed by linking dependent settlement to their respective central places.

Mahendru et al. (1983) suggested a linkage pattern by taking the concepts of total link length, entire route length, and settlement-interaction, link, and route and network efficiency in rural road networks. These parameters were used to generate, analyze and evaluate rural road link patterns.

Rekha et al. (1984) designed a route network for connecting various habitation points to a center like taluka/district headquarters to minimize the distance. Length of all edges, demand from every network, spatial network and permitted deviation factors were considered as inputs. The analysis was conducted with spanning tree basis.

Kumar et al. (1991) developed a planning methodology for systematically generating rural road networks. The primary rural road network was made by providing the connection from each village to a more significant activity center.

Katti et al. (1990) developed a three-tier road system at district levels like nodal roads, radial roads, and link roads. The nodal roads were proposed by connecting taluka headquarters with minimum spanning tree and radial roads by identifying the resultant line of transport potential polygon. Link roads were provided with an objective decision based on the needs.

Amarnath et al. (2011) developed an optimal rural road network using non-hierarchical cluster analysis approach. The algorithm named CLUSTAL was designed for the network generated using the VISUAL BASIC program. In this study, two networks were produced by two methods i.e. cluster analysis approach and utility value approach. Network evaluation was carried out by two methods, graph theory and saturation system. Network developed by cluster analysis yielded better connectivity. Because of the non-presence of agricultural and industrial tonnage data, socio-economic characteristics are not well defined.

Shrestha et al. (2013) suggested a methodology to determine nodal points in rural road network for maximizing the connection from nodal point to villages. They observed the nodal point based upon maximum covering location model and considered the first stage of planning afterward using a minimum spanning tree concept, the connection of all nodal points by the prim algorithm to form a road network. They employed this methodology for the planning of rural roads in Lamzung district in Nepal.

2.4 Review of GIS Applications in Rural Road Planning

Some of the relevant research work, related to applications of GIS in road information system development and planning were discussed in this section:

Prasada et al. (2003) developed a village information system in GIS. This study provided an optimum link to each village with maximum benefit regarding accessibility to a significant village with minimum construction cost.

Mallick (2004) suggested a spatial and attributed database for planning at the block level. The work suggested that the plan of the rural road depends much upon quantity as well as the quality of database available. The primary objective of this study was to identify rural facility center with the aid of GIS tool. The main issue was that data needs would be fulfilled with proper integration of the various data producer, data manager, and data users.

Prasada et al. (2003) Chutia et al. (2004), Durai et al. (2004) Rao et al. (2007), Mishra and Naresh (2009) and Ajay et al. (2013) used GIS in rural road planning and developed an information system of the network. The information of roads, habitation details, and facility availability details were considered in these studies.

Singh (2010) suggested accessibility based rural road network planning to be implemented in GIS. A new index of accessibility was designed, which evaluates various link options according to their efficiency in accessing the missing functions in the unconnected settlement.

Kumar et al. (2011) suggested planning of rural roads based upon upgradation of the rural road using GIS. In this approach, preparation of rural road network was based on the integration of villages with facilities like schools, hospital, post office, warehouse etc. for development of socio-economic status and to provide necessary needs to village population within accessible distance. This upgradation of rural roads includes giving closest facility routes for every village and providing new facilities wherever necessary.

Tatababu et al. (2015) demonstrated the use of geospatial technology for identification of optimal connectivity level between headquarter and district headquarter. They analyzed double lane connectivity for maximizing socio-economic benefits. Patil et al. (2015) carried - out a study related to transportation network analysis by GIS for ascertaining transportation facilities.

Vinod et al. (2003), Panahi and Delavar (2008) and Alazab et al. (2012), Praveen et al. (2013) conducted transport network analysis using GIS and developed an optimal route, representing the total cost of the route in meters as well as in minutes. They found that network analysis helps in emergency situations. The network analysis was carried out by considering the distance between the two points.

2.5 Review on Evaluation of Road Network by Vulnerability Analysis

The vulnerability of a transportation network, a performance measure of a system or component, plays an essential role in the transport network evaluation for efficient allocation of resources. Disconnection is the most severe problem after a natural disaster. Due to failure in connectivity, difficulties arises in rescue and evacuation, there is the question of post-disaster support, and it raises also the transportation cost and the loss on the economy.

Vulnerability analysis has been carried out in the network by identification of critical links. Several practical methodologies were proposed for the identification of critical links in the network. Taylor et al. (2006) suggested the evaluation index based on accessibility of a node. Accessibility index of a node was calculated for two different scenarios at normal condition and the likely failure of each link, one at a time. The critical link is that link which has higher change in accessibility in a locality at the time of failure assumption.

Jenelius et al. (2006) introduced the concept of vital link. The primary decision factor was based on a change in total travel cost between link failure condition and normal condition. The link importance was computed with the assumption of link failure at a time and total difference in generalized travel cost in a network. The link having a higher change in generalized travel cost was prioritized first.

Scott et al. (2006) proposed a methodology based on Network Robustness Index (NRI) to identify the critical link in a road network. Network Robustness Index (NRI) was calculated by calculating the total change in travel cost after removing a link in a network and higher the value, higher the criticality. Travel time and traffic flow were calculated based on user equilibrium assignment model after assumption of each link failure.

MLIT (2011a) gives an evaluation methodology for the evaluation of redundancy by using detour ratio. Disaster prevention function were categorized for each link, such as level A that is highly protected and level D which has the highest risk of disaster. A detour ratio was introduced for the evaluation of redundancy. Individual Links cannot be compared with each other so that it cannot prioritize the links.

MLIT (2011b) published a manual for the evaluation of road network under emergency condition. The model estimated the total travel time in a network before and after disaster and the index calculated was the ratio of whole travel time under disaster condition to total travel time under normal condition. The selection of link was a crucial part and was identified based on the probability of damage. However, it does not consider any numerical value of expectation, but only determines the point where traffic cannot pass during the disaster.

2.6 Discussion

Different authors have developed various models and methodologies for addressing rural road problems. These studies have limitations in specific contexts. The following discussion will identify the boundaries of the existing models and find a possible way of addressing the problem rationally.

The model developed by Kumar and Tilloston (1985) operates on the simple data of population and linear distances between the villages which can be very relevant to a study addressing the rural road network planning in hilly regions of a rural area. It gives useful information on relative construction and travel costs based on length of a link and population connected by the link. Person-km has been introduced to take into account travel costs in a link which could be a basis for selecting the optimum rural road network.

Oudheusden and Khan (1987) proposed quantitative and qualitative approaches which exist in decision making and cannot ignore them both. Based on these methods, a decision model was introduced to enable optimization of all-weather access to a local market or a provincial road network, under the budget constraint. It was a practical concept for many rural road situations in developing countries, where funds are insufficient to connect all villages by roads. A rural road network model proposed by Makarchi and Tilloston (1991) connects every village to the surrounding road network and which minimises the sum of the construction costs and the travel costs. However, they realized that the problem was complicated by the lack of data on travel costs. While Kumar and Tilloston (1985) used the concept of person-km to take effect of travel costs.

In a user-friendly rural road planning model, Kumar and Kumar (1999) proposed a simple parameter to evaluate road links; the population served with unit investment. This approach was straightforward, and data can be collected efficiently. The link serving higher community per unit investment receives top priority during evaluation. Further, Kumar and Kumar (1999) estimated that road connection from each village to at least the nearby market centers and education facilities amount to 93 percent of the rural trips. Identification of nodal points for a rural road network in rural areas was a difficult task as rural road links cannot connect all the villages. It can also be a reasonable basis for identification of nodal points for a rural road network in rural areas.

The Integrated Rural Accessibility Planning (IRAP) methodology (IRAP, 2002) was used to collect data for planning works in small areas. However, Accessibility Index (*AI)* can be a valuable tool for prioritization of road links. For regional level planning, data from settlement level may not be relevant and could be a huge. The IRAP method may be suitable for village level transport planning based on the household information. The technique requires a massive volume of data which is time-consuming and costly. It was a highly participatory approach which may not be practical for regional level planning. In settlement based interaction model for rural road network planning (Shrestha and Routray, 2002); the central places and existing roads, tracks and trails were the basis for rural road networking. The missing linkages can be identified based on present and potential nodal points and existing links and estimation of the transport demand by establishing a relationship with centrality index and intensity of interaction in this method. The GIS-based rural road network model (Singh, 2010) was based on accessibility concept and generates connectivity pattern for unconnected settlements based on travel costs concerning person-km. It can be a beneficial concept for rural road network planning. However, this method also requires large data from settlements for each function (service) to calculate an index of accessibility accessing the missing features in the unconnected settlement.

2.6 Scope of the Present Work

It is clear that all the settlements in rural areas cannot connect by rural roads due to spatial and financial constraints. However, these settlements should have access to roads. Although all the settlements cannot be connected, a rural road network can reach near the settlements. Hence, connectivity/accessibility to rural settlements in rural areas has to be defined differently so that the rural road network can cover all the settlements within a proper distance from the system. This kind of issue is rarely addressed in existing rural road network planning models. It is the main gap identified in rural road network generation in literature. The rural road network problems can be addressed concerning connectivity/accessibility by carrying out vulnerability analysis. It can be a realistic and practical way of solution to the issues.

2.7 Summary

In this chapter different research works in rural road planning are discussed. From the discussion, it is observed that rural road problems should be dealt more with social indicators rather than economic indicators. The primary social index is population (of settlements) covered by a rural road link. One of the advantages of using this index is that the population data can be easily obtained from census data. In line with this, populations covered by a road link (Kumar and Kumar, 1999) can be taken as significant indicator to be considered to take into account the socio-economic benefits from the rural road links. The other factors can be costs (construction costs and travel costs). However, these factors cannot be assessed precisely for rural areas. Hence, costs can be considered indirectly taking distances (construction cost) and the person-km (travel costs) (Kumar and Tilloston, 1985; Makarchi and Tilloston, 1991; Singh, 2010). Connectivity/accessibility can be taken as benefits from the rural roads as indicated by previous models.

Chapter 3

RESEARCH METHODOLOGY

3.1 General

In some states of India, the group of villages constitutes a ‘mandal' and group of ‘mandals' represent a district. Group of districts forms a state. Since it is not feasible to study the infrastructure available for only one village, it is proposed to study the infrastructural availability of the mandal and also to prepare the geospatial database for the mandal as well as the district level. For creating the geospatial database, it is necessary to develop various layers for the mandal such as infrastructure details, road details, and cross drainage details. Infrastructure locations and missing road links are traced using hand held GPS instrument.

3.2 Methodology Adopted

With the above background, literature review and objectives discussed, the methodology was prepared for the efficient planning of rural road network. The main stages involved in the present research work are database preparation, spatial analysis of facilities, design an optimal road network and evaluation of network. The methodology adopted for the current study is presented in Figure 3.1 and discussed in subsequent sections.

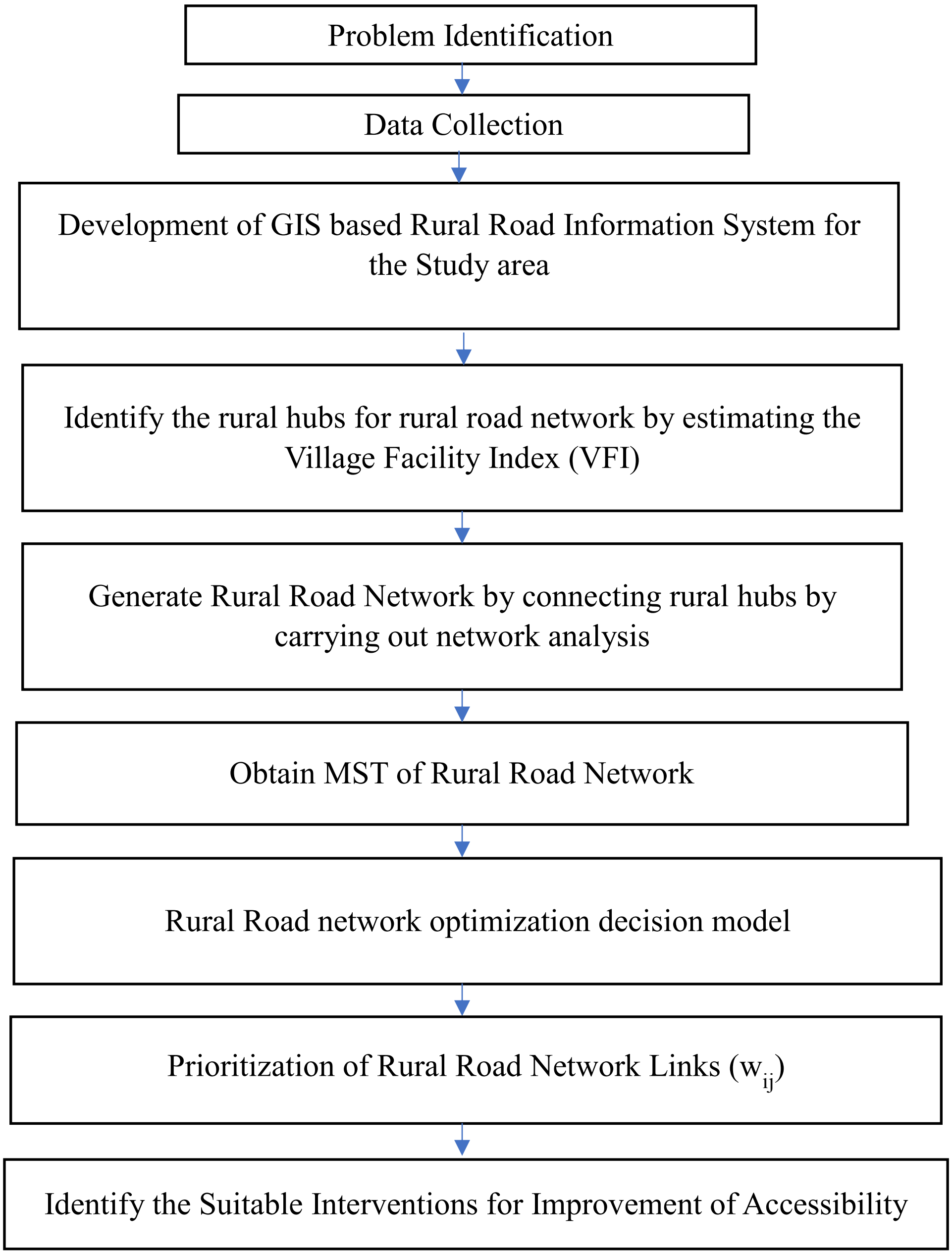

Figure 3.1: Proposed methodology for rural road network planning process

3.2.1 Study area profile

Erstwhile Warangal district in Telangana state, India has been selected as the study area. The district is situated between 78° 49' and 80° 43'E of eastern longitudes and 17° 19' and 18° 36'N, of northern latitudes and is shown in Figure 3.2.

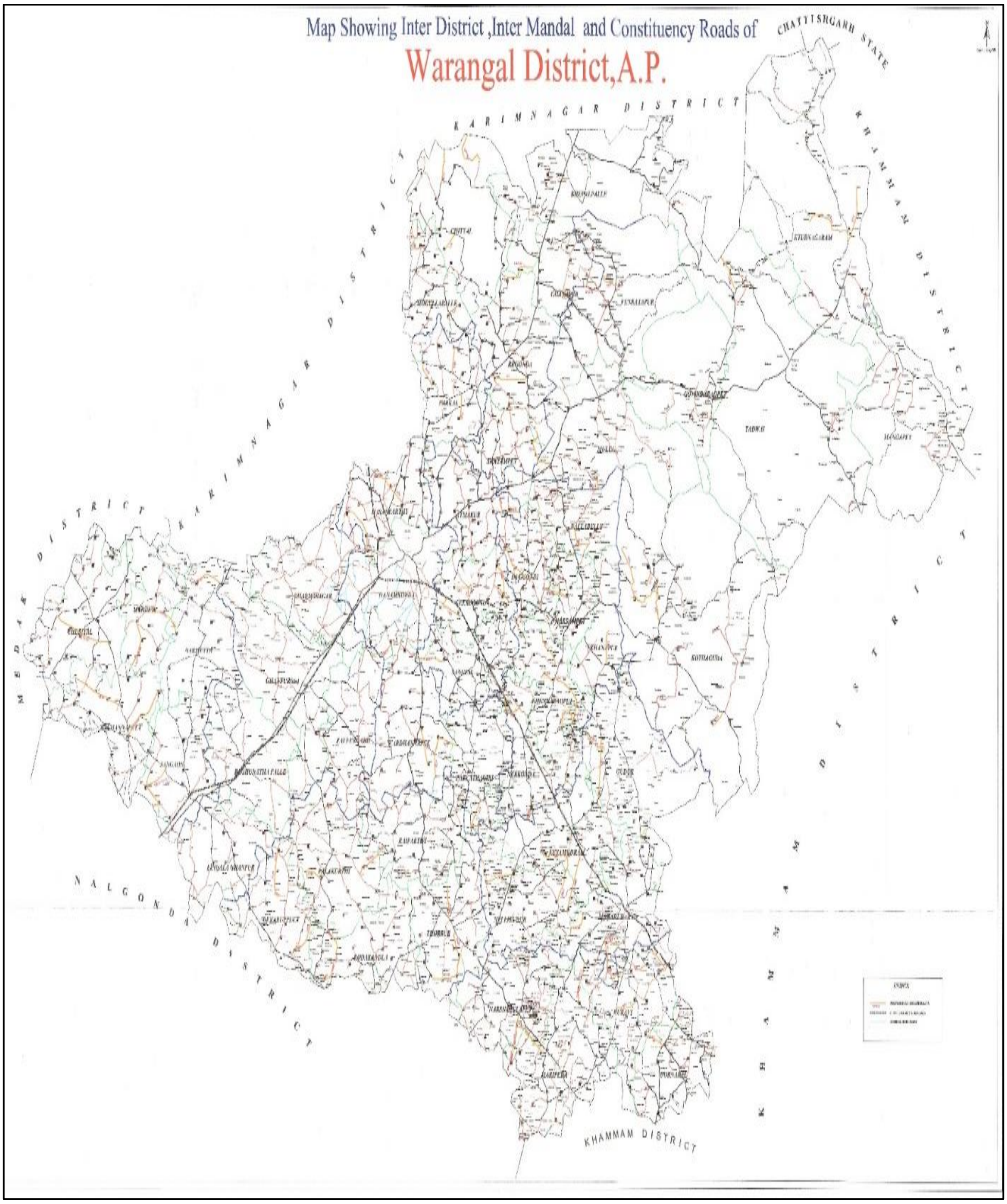

Figure 3.2: Connectivity status of the study area (source: Panchayat Raj department, Telangana)

The study area has 67% connectivity with roads and the connectivity status of the study area is shown in Figures 3.3 to 3.5.

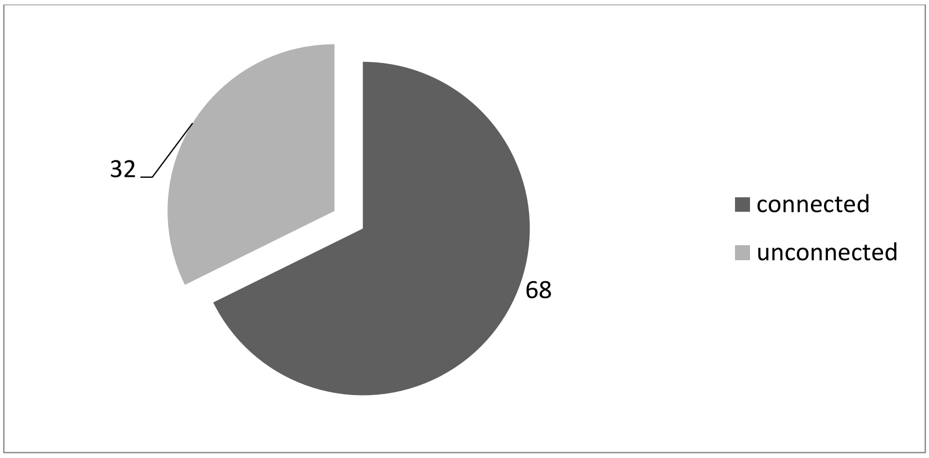

Figure 3.3: Connectivity statuses of the habitations in the study area

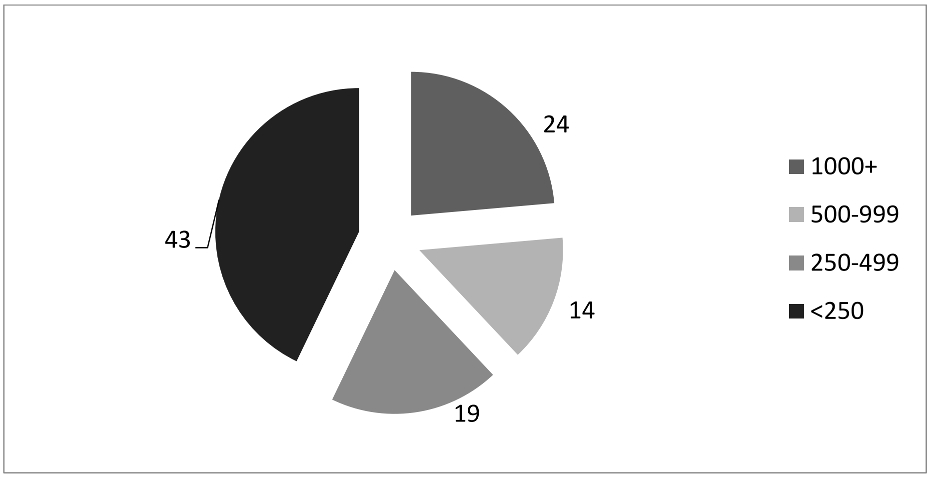

Figure 3.4: Size of connected habitations in the study area

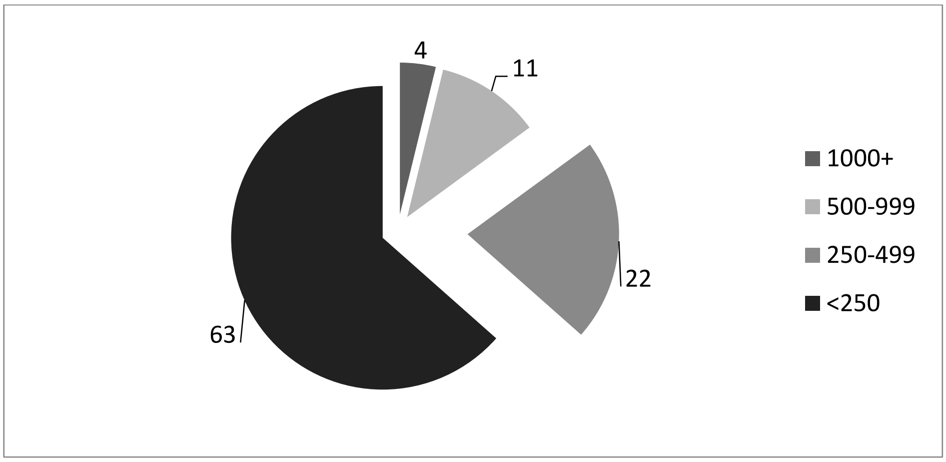

Figure 3.5: Size of unconnected habitations in the study area

In the present study, travel time for each link was collected from the field. The field surveys were conducted by traveling on each road twice in a year, i.e., before and after the rainy season in both the directions. Handheld GPS instrument was used to collect the location of facilities and settlements in the study area. Secondary data like toposheet, habitation details as well as road information data and other ancillary data were collected from Panchayath Raj department of Warangal district. Survey of India (SOI) topographic sheets were used to prepare different layers of the study area.

From the existing data it is observed that Hasanparthy block has the highest connectivity with 97% and Nellikudur has the lowest connectivity with 54%. In the study area still 38 manadals have connectivity of less than 75%.

3.2.2 Data collection

Significant steps in data collection include (i) groups of spatial and non-spatial data to prepare the database, (ii) preparation of the database, (iii) creation of rural road database by integrating the spatial and non-spatial data. The SOI toposheet at the scale of 1: 50000 and the PMGSY road network map prepared by Panchayath Raj Engineering Department were used to collect spatial information of rural roads of the study area. GPS instrument was used to trace the roads which are not shown in PMGSY map. The location of Cross Drainage (CD) structures were identified using GPS. The geospatial features were prepared using ArcGIS software. Road inventory details, pavement details, existing cross-drainage structure details, photographs, and videos were collected to create the attribute database. Road inventory data like road name, length, link number, etc., pavement details like type, width, condition, etc. and existing cross-drainage work details like type, width, and conditions were recorded. Photographs and videos of the road were added to the information system. The survey sheet used in this study is presented in Appendix A. Photographs are captured from the field while collecting the data as shown in Figures 3.6 to 3.8

Figure 3.6: Identification of critical links and missing links from villager’s information

Figure 3.7: Discussion with Panchayat Raj engineers regarding the road network

Figure 3.8: Location identification of infrastructure using GPS

In this study, different hardware and software were used to achieve the objectives of the study as indicated in Table 3.1.

Table 3.1: List of Materials Used in the Study

No	Hardware/software	Purpose
1	Handheld GPS (Trimble)	Primary data collection
	Scanner	Converting hard copy to soft copy
	Printer	Printing documents
2	ArcGIS (version 10.1), ArcMap, ArcPay	Building geo-database and network analysis
	MS-Office (MS-Excel)	Prepare turntable and solve the mixed integer programming.

Geographic Information System (GIS) is a powerful tool for storing, assembling, analysing and retrieving data in an efficient manner. ArcGIS (version 10.1) was used for the analysis of road network in this study. This extension was used for routing applications. In this study, one feature of this expansion named as, "New Route" was used to determine the shortest path or quickest path in the road network. Arc Pay was used to write python script to generate the Minimum Spanning Tree (MST) of the network. In the present study, Trimble Geo XM 2005 series (see Figure 3.9) was used. This instrument has an accuracy of 1 to 3 meters. In this study, it was used to collect the exact locations of CD works and rural infrastructure such as banks, educational facilities, market facilities, temples, medical facilities, public facilities, post office, bus stops, railway crossings, and Grama Panchayath Offices.

Figure 3.9: Trimble Geo XM 2005 Series

3.2.3 Development of Rural Road Information System (RRIS)

The data was collected from the primary and as well as from the secondary sources and used for the development of RRIS for the study area. RRIS was developed to generate maps, which would provide relevant information for developmental activities and to act as source information authentication about the roads and villages in the mandal and the management of rural road related information in a technological environment.

3.2.4 Buffer analysis and identification of rural hubs

Spatial analysis was performed for defining the coverage distance from each facility. For defining coverage distance for each facility, buffer analysis was carried out for all facilities in each mandal. Buffer analysis was performed for all sub-facilities of different core facilities such as educational, medical, transportation, communication and market facilities for different service distances. Desirable Coverage Distance to Facility (DCDF) values were identified from the spatial analysis of facilities. Identification of rural hubs is done by calculating the Village Facility Index (VFI) of habitation. The VFI of habitation is estimated by the cumulative value of different facility indices like education facilities, medical facilities etc. The village having the highest VFI value and connected with at least one through rout is considered as Rural Hub (PMGSY II 2015). Weighted index method was used to determine the VFI.

3.2.5 Minimum travel path analysis and optimal road network

Minimum travel path analysis is carried out in the network towards different public facilities like rural hub, medical facility and administrative center etc. ArcGIS 10.0 software was used for this analysis. This analysis was carried out by network analysis tool by concerning travel time between two locations connected through the existing road network. The shortest paths towards rural hubs were identified using Dijkstra algorithm (1959). This analysis is carried out by considering the travel time. The travel times are taken from the field by travelling along the route.

Minimum Spanning Tree (MST) is obtained, using Prim's Algorithm (see Appendix B). The MST of network represents the minimum connection level necessary for the rural accessibility of a specified coverage distance. MST of network represents the optimal network of the study area. Customized ArcGIS and ArcPay tools were used to write the python script for the development of MST.

3.2.6 Prioritization of the links and budget allocation

In this study planning for prioritization of links is achieved by considering two different approaches.

i. Population considered as proxy
ii. Vulnerability analysis

The parameters i.e. Population served by links, Person-km, Population served/km and vulnerability of link are considered in this study. The vulnerability is calculated by change in accessibility after failure of a link.

3.3 Summary

In this chapter, methodology was presented in detail. The steps involved to achieve goals were buffer analysis, minimum travel path analysis, and identification of rural hubs, network optimization, prioritisation and budget allocation. Identification of rural hubs are explained in detail in subsequent chapter.

Chapter 4

IDENTIFICATION OF RURAL HUBS

4.1 General

Geo-database is the integrated spatial and non-spatial database. It is developed from spatial and attribute data. In the present study, spatial and non-spatial databases were developed separately and integrated to build habitation detail infrastructures information system. The methodology for identifying rural hubs is shown in Figure 4.1.

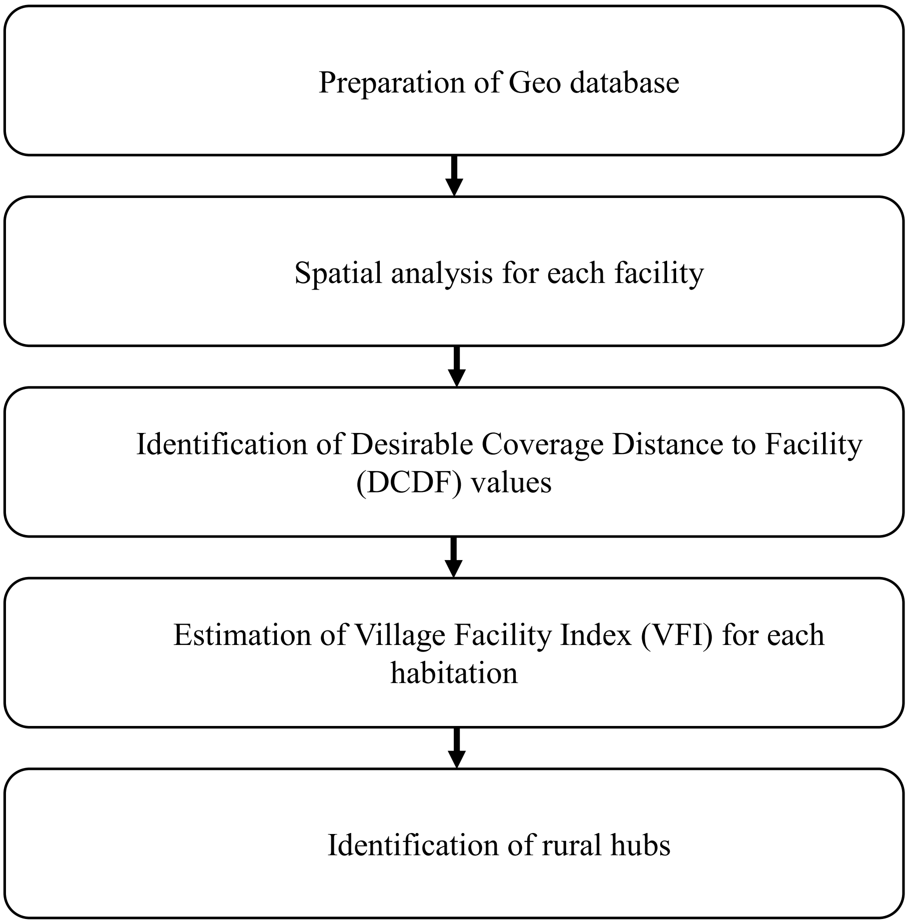

Figure 4.1: Flow chart for identifying rural hubs

4.2 Preparation of Geo-Database

In general, people use GIS for four primary purposes: data creation, display, analysis, and output. Users can display objects according to the data in the database. Output options include cartographic-quality maps as well as reports, lists, and graphs. Three main components of geographic data considered in this study include geometry, which represents the geographic features, i.e., points, lines, or polygons (areas) associated with real-world locations.

4.2.1 Preparation of Spatial Database

To prepare the spatial database, preliminary, SOI map of scale 1: 50,000 for the study area collected from Panchayat Raj Department of Warangal District. The map was scanned and entered into the GIS environment for registration purpose. After Geo-referencing, different features of the study area were digitized as different layers. These layers were created in Arc Catalog environment according to the feature type; point layer for the location of habitations, rural infrastructures, etc., polygon for a Mandal boundary, and line for road and other linear features. The road which was traced out from the field using GPS instrument was imported into the map and digitized as a line feature. The shape files were created for various features like habitations, roads and different facilities. Once the required shape files of different layers are created, digitization of features is done. Digitization is the process of converting the geographic features on an analog map into digital format.

4.2.2 Non-spatial Database

Non-spatial data are tabular or textual data describing the geographic characteristics of features. The attribute data can be stored in Excel or Access spreadsheets and joined to their corresponding spatial features using GIS capability. The data were entered into the database for all features collected via field survey and digitized from toposheet. The database contains information about the road details, pavement details, habitations, rural infrastructures, etc

The geo-database was developed for Hasanparthy mandal, as explained in this chapter. The connectivity status of the study area, the different types of roads constructed from the various programs, represented with different legends, are shown in Figure 4.2.

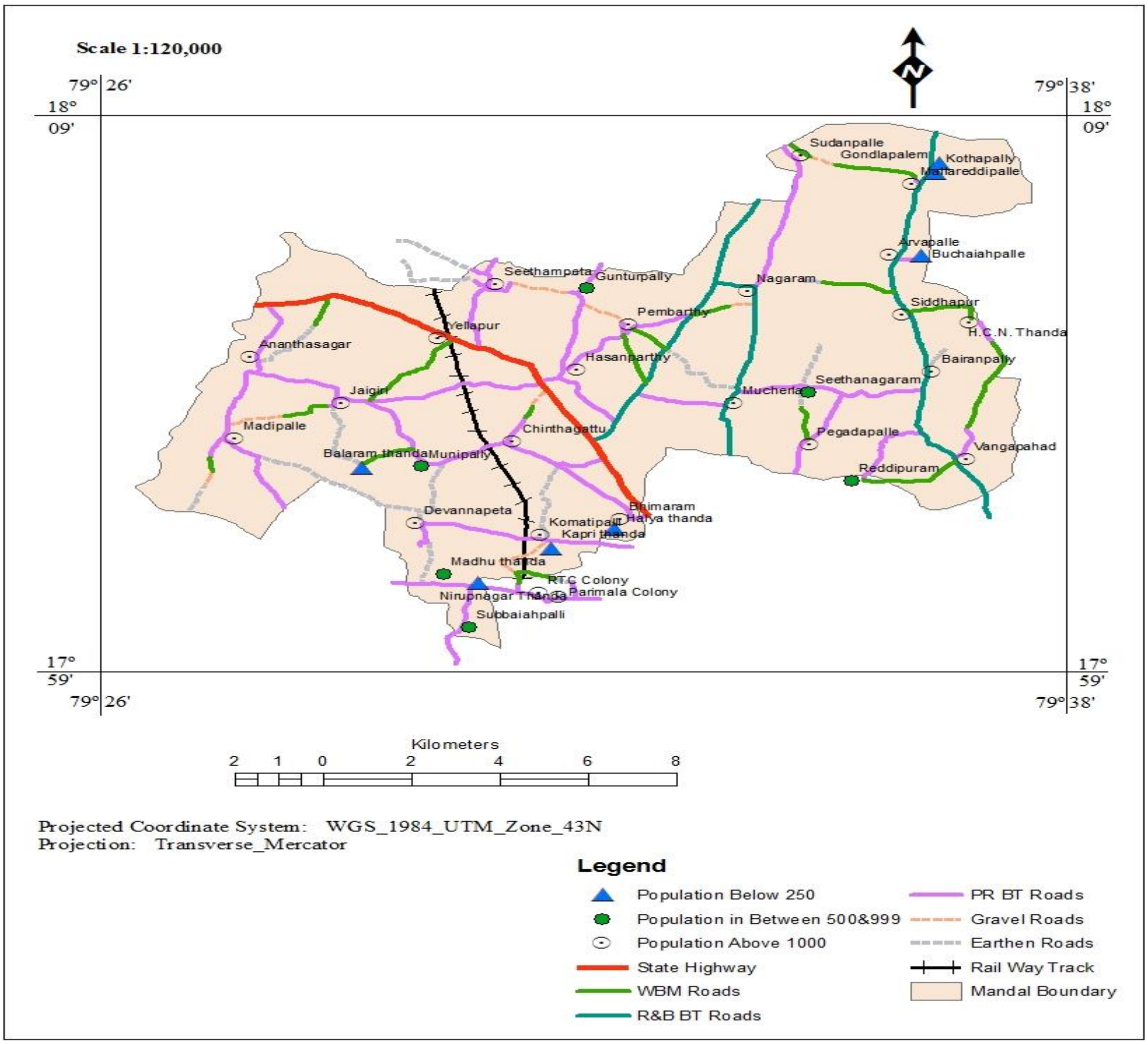

Figure 4.2: Connectivity status of the Hasanparthy block

Figures 4.3 and 4.4 represent the snapshots of habitation and road inventory details of the road network of the study area in GIS environment.

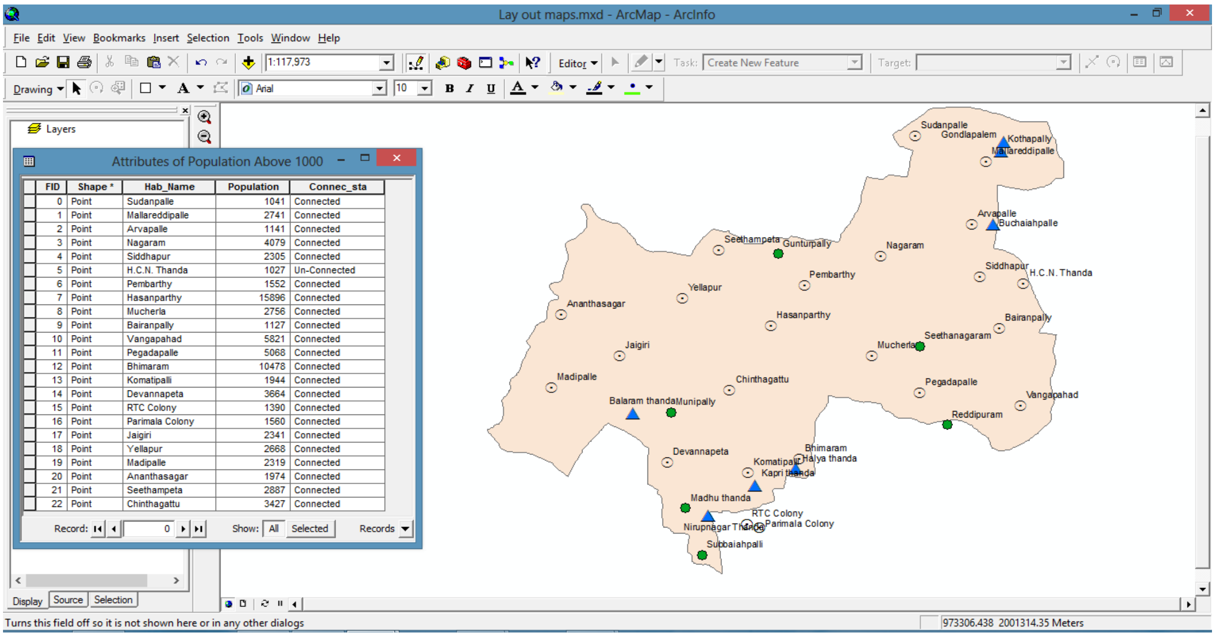

Figure 4.3: Habitation information of the study area

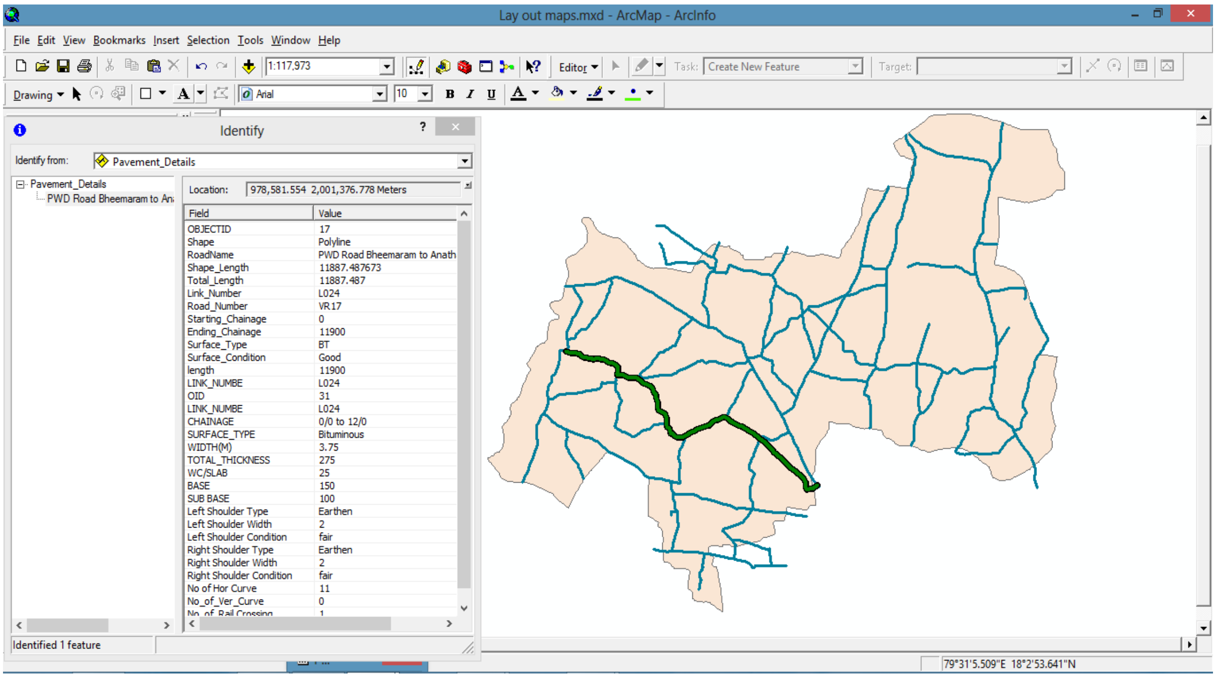

Figure 4.4: Road inventory details of the roads in Hasanparthy block

The location of CD work's, the road network of the study area and the percentage distribution of Cross Drainage works are represented in Figure 4.5. The location of CD works were collected as a point feature from the field using GPS instrument and entered into the GIS environment.

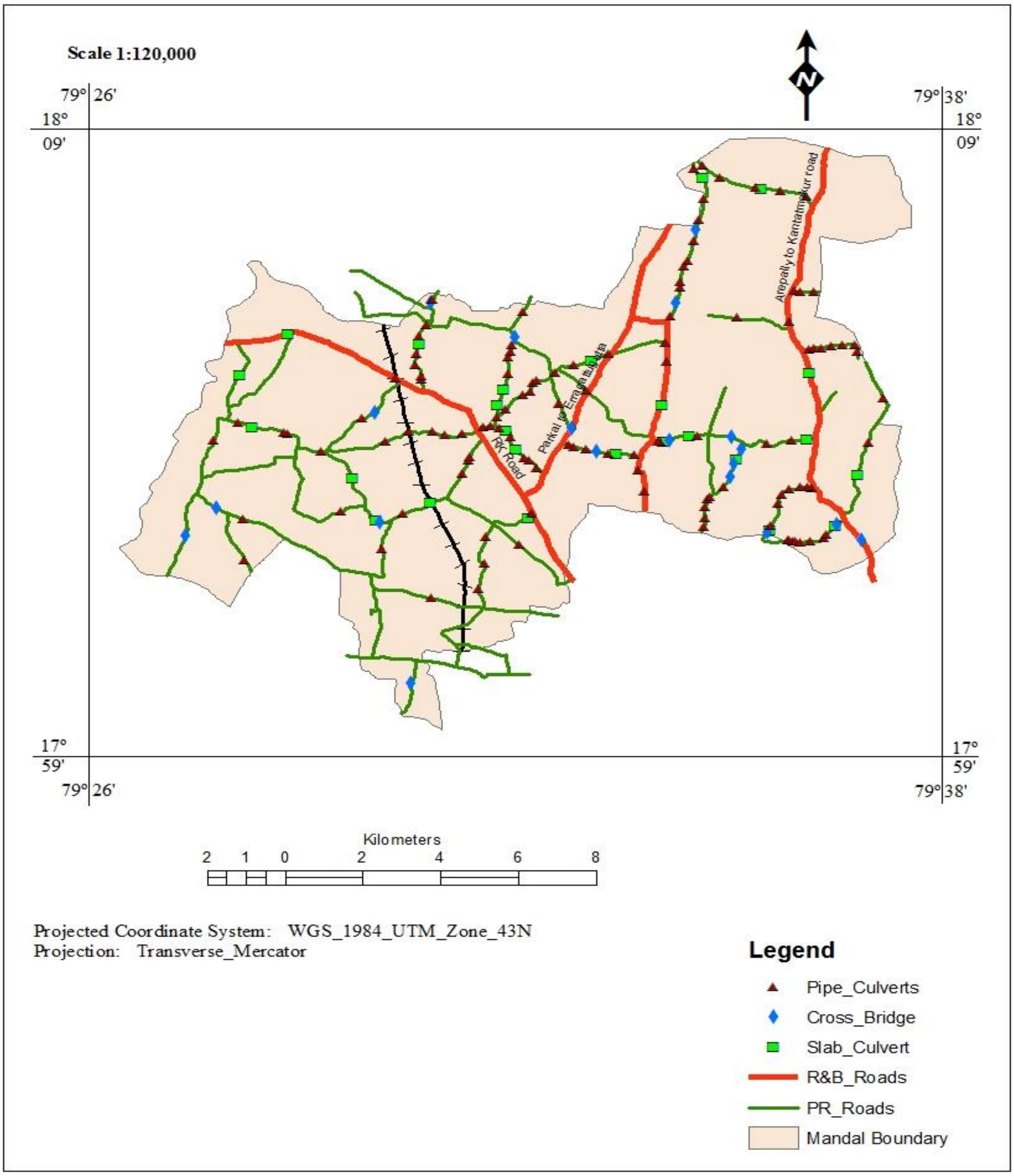

Figure 4.5: Cross Drainage locations in Hasanparthy block

The different facility locations were identified using GPS in the study area and are represented in Figure 4.6. Photographs and videos of roads were attached to the shape files. This information will be helpful for the authorities to make vital decisions.

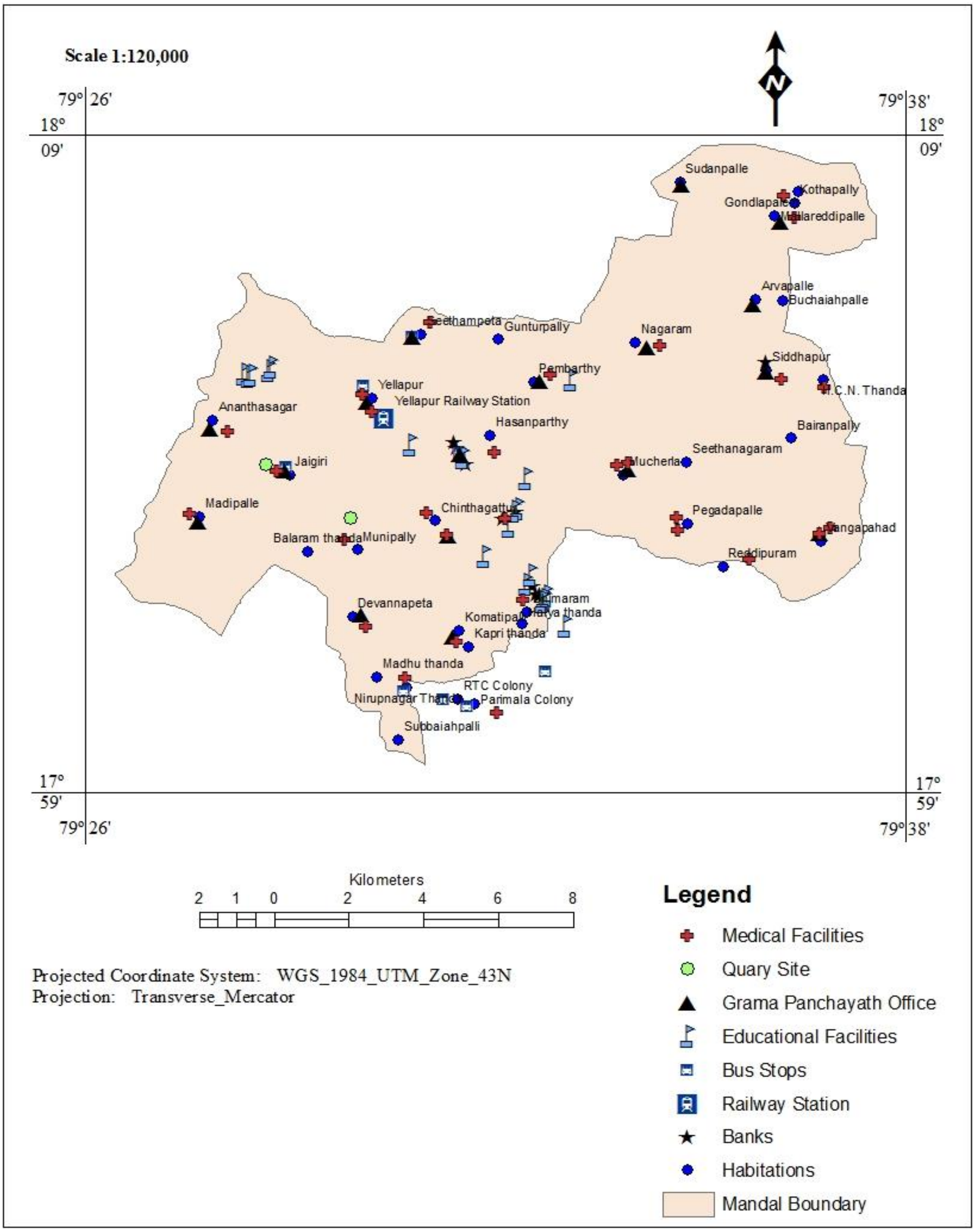

Figure 4.6: Facility infrastructure details in Hasanparthy block

4.3 Spatial Analysis for Defining the Desirable Coverage Distance of the Facility (DCDF)

Spatial analysis was performed for defining the coverage distance from each facility. For defining coverage distance for each facility, buffer analysis was carried out for all facilities in each mandal. From this study, many habitations covered from a facility at different distance levels are noticed. For performing buffer analysis, first the initial distance is fixed for each facility based upon availability of service in the mandal and increased distance as the suitability of captured population.

Buffering was carried out for each facility in each block of the study area for different distances. For example, Figure 4.7 shows the accessibility levels of the habitation from the high school. Similarly, for all the facilities the buffering operation was carried out. According to the Report on Village Facilities (RVF 2002), the allocation of facilities in rural areas should cover at least 80% of the population. In this study, Desirable Coverage Distance of the Facility (DCDF) values were identified from the spatial analysis of facilities, at what distance the facilities cover at least 80% of the population.

Buffer analysis was carried out for each facility, and the summary of results are shown in the appendix B. Buffer analysis was carried out for primary school, and the results are shown in Figure 4.8. The figure shows that the more than 50% of the population were covered in less than 500m and then increment levels with 12%, 5%, 4% and 2.89% as the distance levels increased by 500m step size.

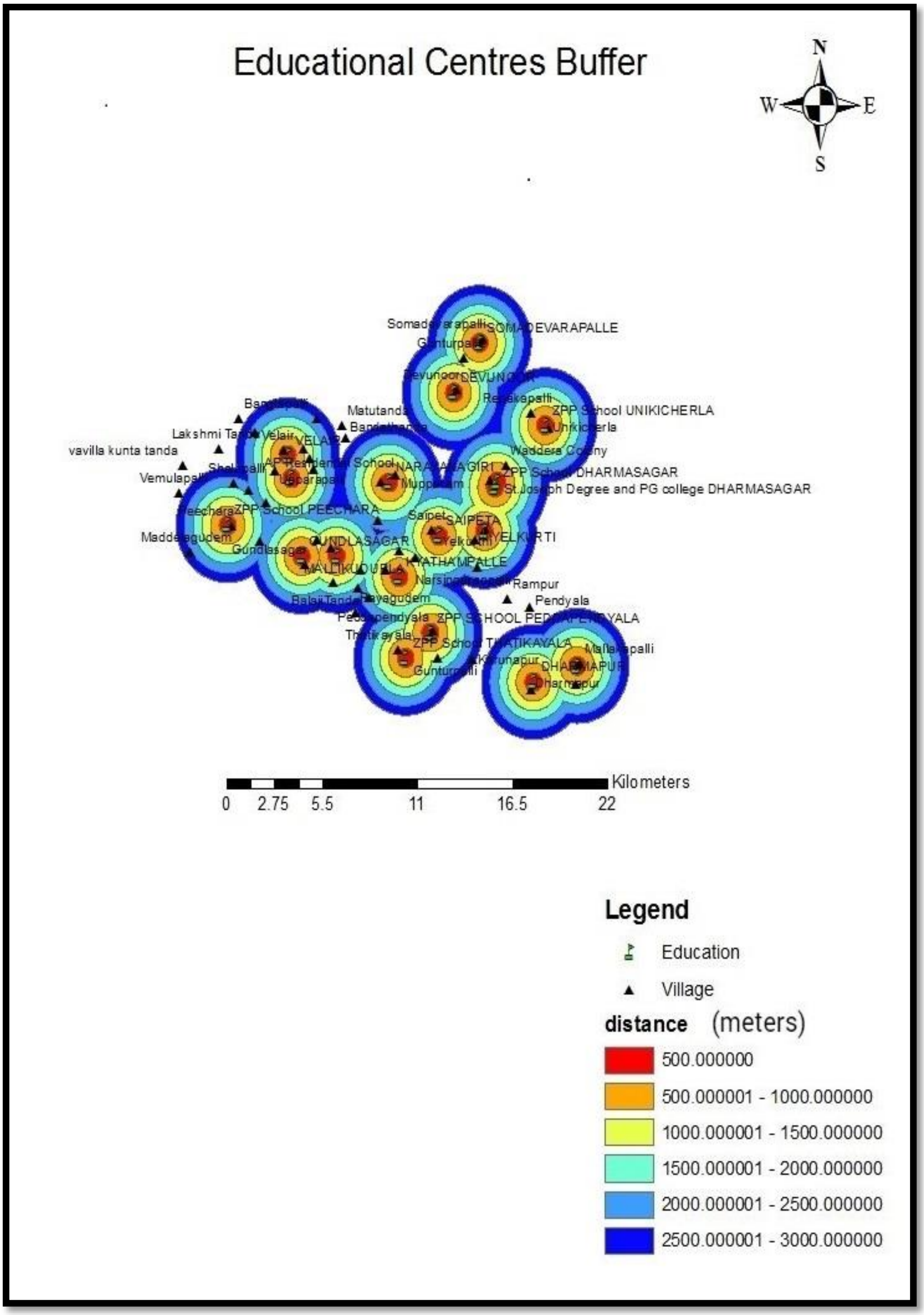

Figure 4.7: Accessibility levels from the high school facility

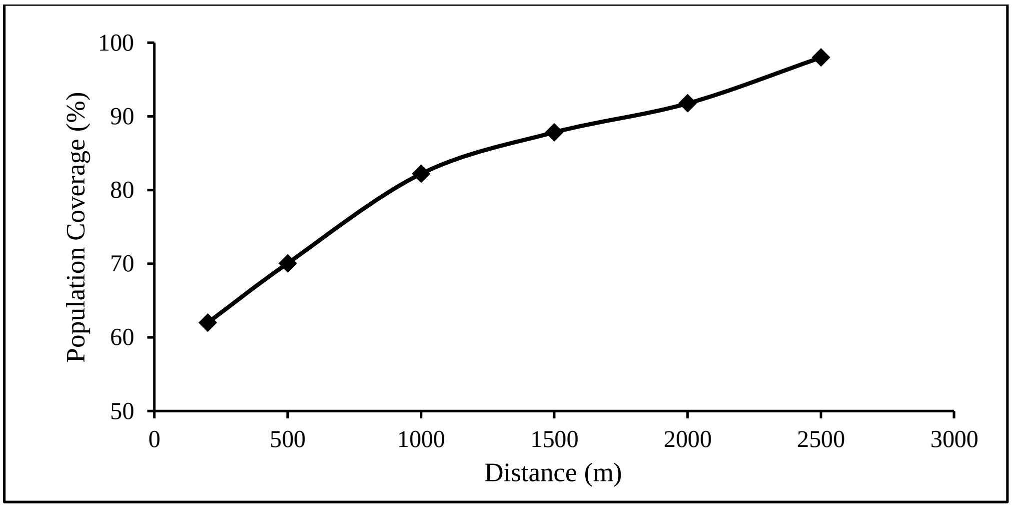

Figure 4.8: Population coverage vs. Distance for the primary school

The DCDF for primary education from the graph is fixed as 1000m at which the facility covers more than 80% of the population and the increment level of population coverage after this is low.

Similarly this analysis was carried out for all the facilities to fix the DCDF values and the results are shown in Figures 4.9 to 4.18.

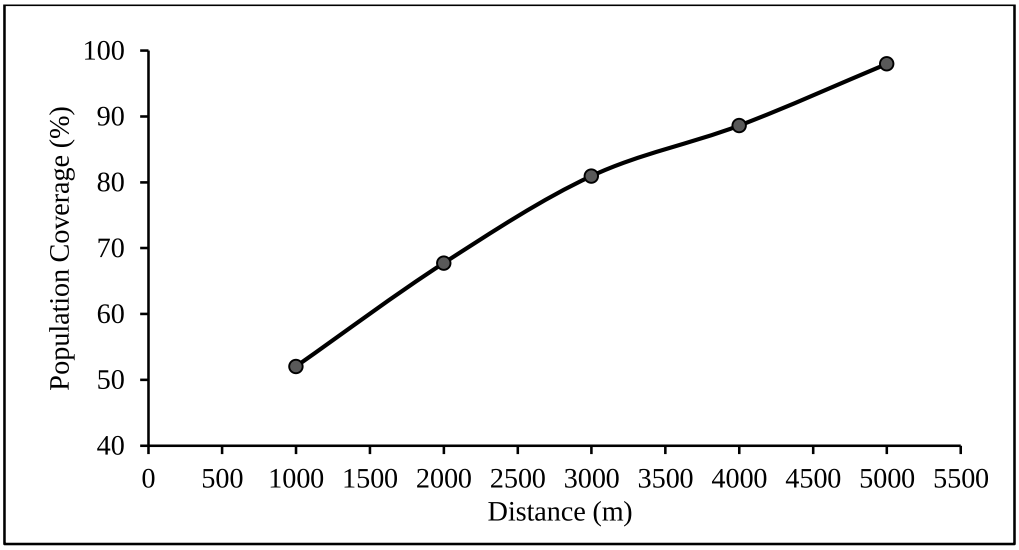

Figure 4.9: Population coverage vs. Distance for the middle school

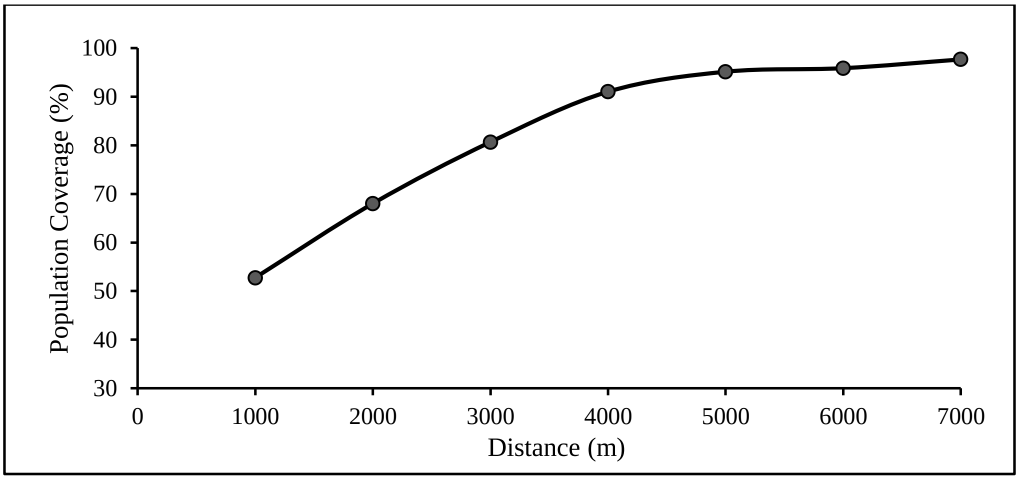

Figure 4.10: Population coverage vs. Distance for the high school

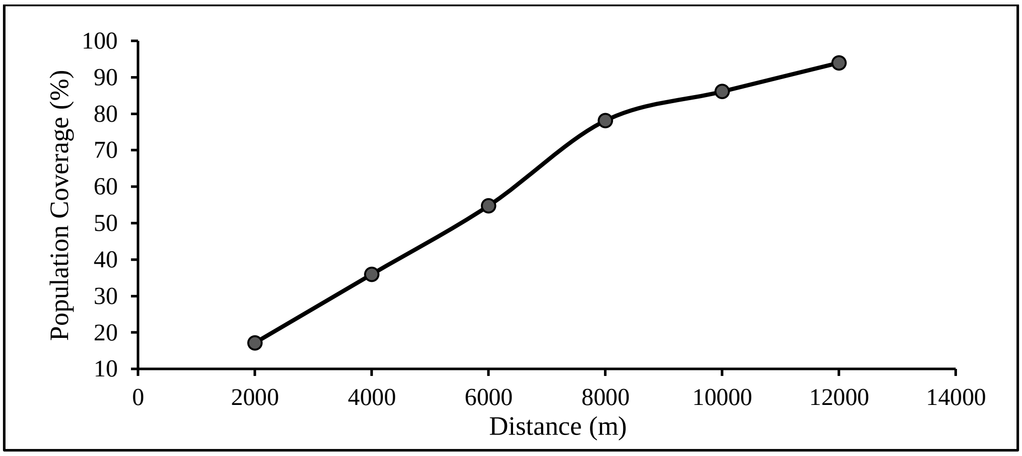

Figure 4.11: Population coverage vs. Distance for the degree college

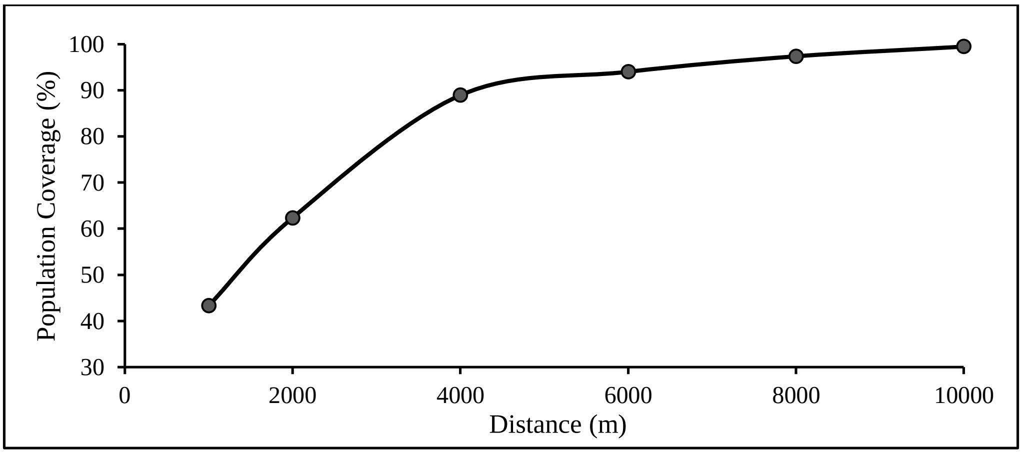

Figure 4.12: Population coverage vs. Distance for the ANM center

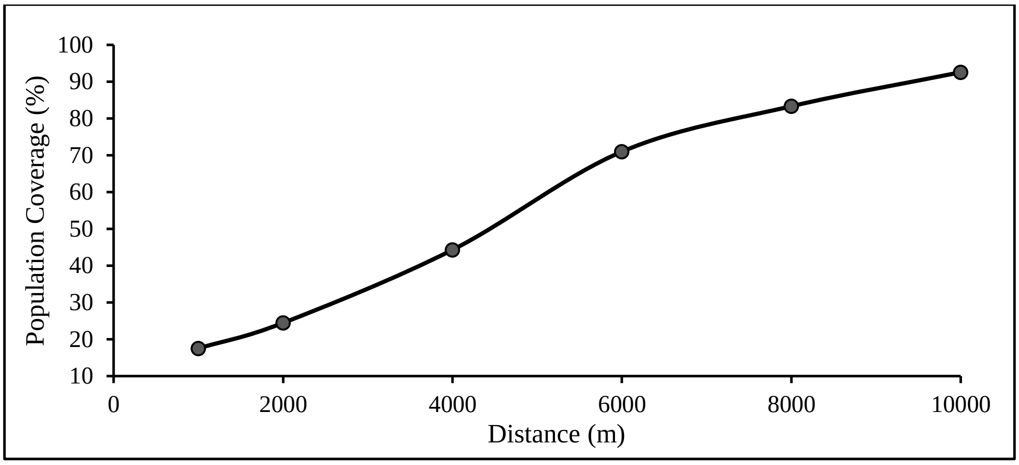

Figure 4.13: Population coverage vs. Distance for the PHC center

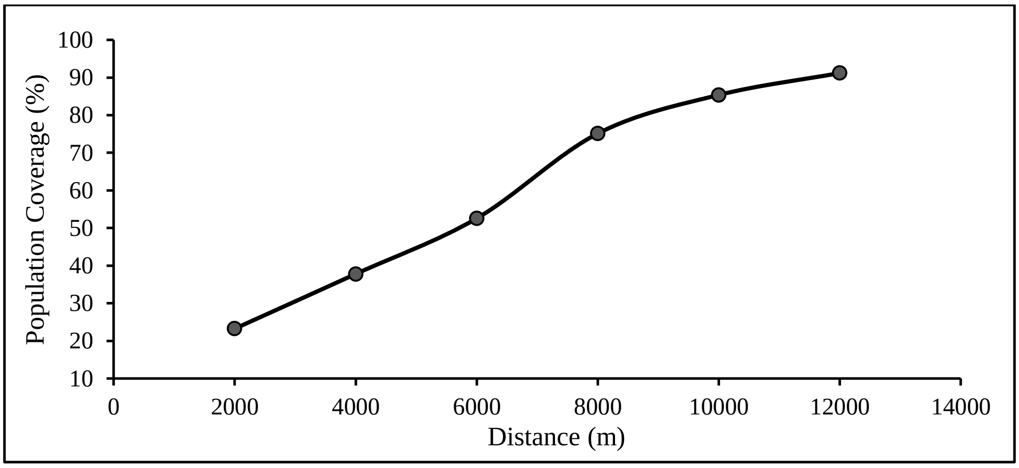

Figure 4.14: Population coverage vs. Distance for the CHC center

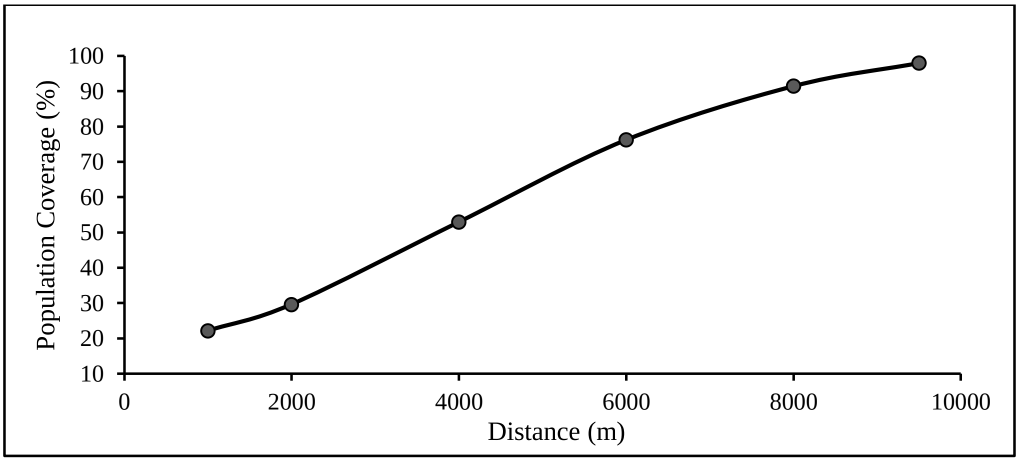

Figure 4.15: Population coverage vs. Distance for the veterinary hospital

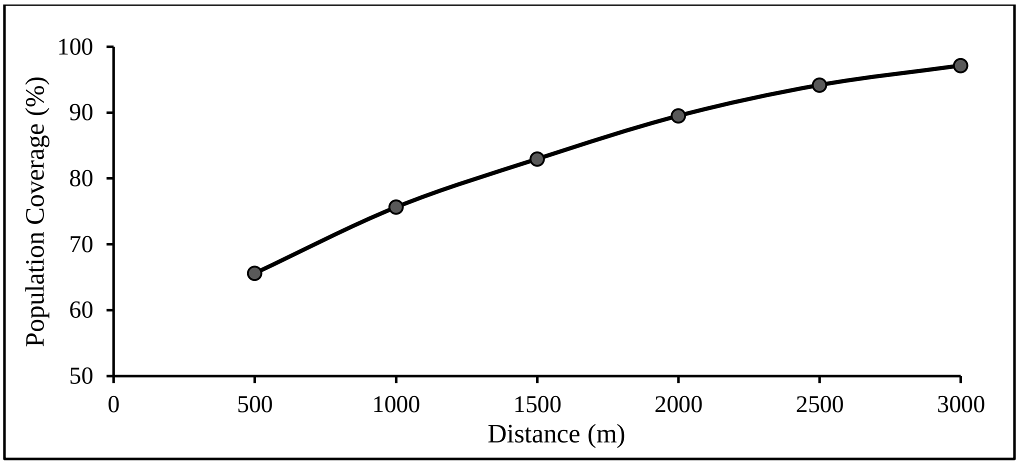

Figure 4.16: Population coverage vs. Distance for bus stand

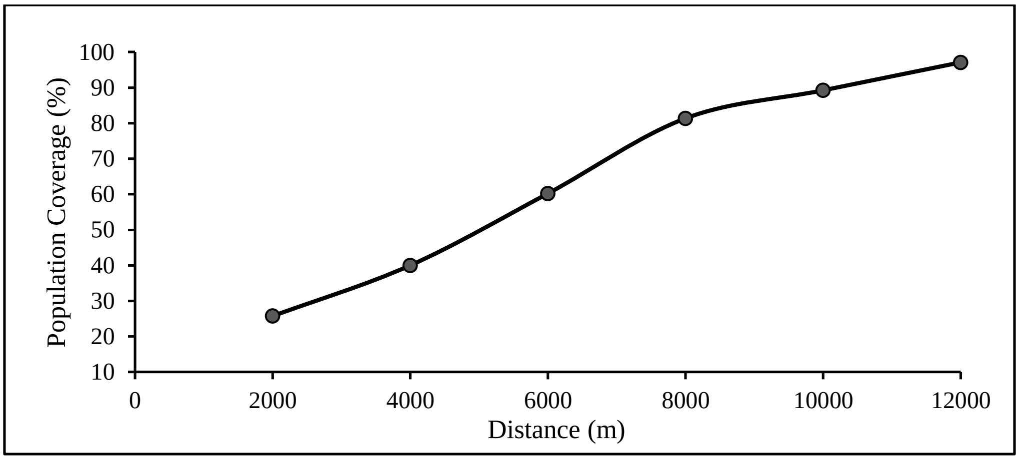

Figure 4.17: Population coverage vs. Distance for ware house

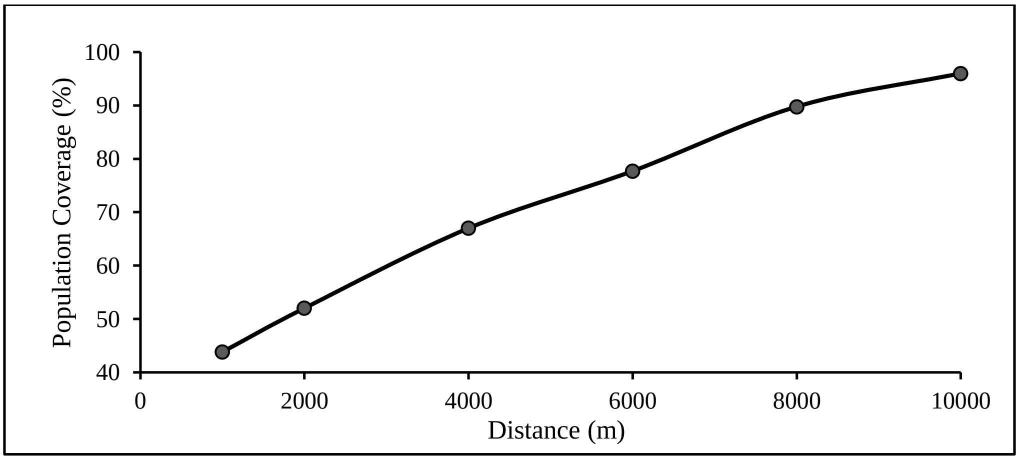

Figure 4.18: Population coverage vs. Distance for post office

Summary of the results by population coverage approach for each infrastructural facility is presented in Table 4.1.

Table 4.1: Population Coverage from Different Facilities

S.No.	**Facility type**	**Average coverage in percentage (%) at a distance of**																							
		500 m	**1000 m**	**1500 m**	**2000 m**	**2500 m**	**3000 m**	**3500 m**	**4000 m**	**4500 m**	**5000 m**	**5500 m**	**6000 m**	**6500 m**	**7000 m**	**7500 m**	**8000 m**	**8500 m**	**9000 m**	**9500 m**	**10000 m**	**10500 m**	**11000 m**	**11500 m**	**12000 m**
1	**Primary School**	70.07	82.21	87.85	91.77	94.66	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	**Middle school**	42.13	52.06	60.12	67.75	74.23	80.97	84.76	88.63	90.23	93.16	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	**High school**	40.45	52.76	60.56	68.02	72.76	80.68	84.15	91.04	93.27	95.15	95.88	97.88	-	-	-	-	-	-	-	-	-	-	-	-
4	**Intermediate college**	-	14.96	16.78	17.15	22.32	26.41	30.14	35.94	40.00	45.58	50.27	54.74	60.00	65.42	70.01	78.10	80.42	84.04	85.24	86.07	88.12	90.00	91.62	93.96

5	**ANM center**	30.12	43.30	50.14	62.35	70.45	75.98	82.14	88.93	91.24	93.51	93.78	94.02	94.54	95.14	96.65	97.34	-	-	-	-	-	-	-	-
6	**PHC Center**	10.24	17.47	20.00	24.39	28.95	34.08	38.41	44.25	50.24	59.99	65.32	70.95	74.12	78.95	80.00	83.29	86.75	88.12	90.00	-	-	-	-	-
7	**CHC Center**	17.12	20.29	21.32	23.25	25.56	30.23	34.25	37.80	39.24	42.35	46.85	52.58	60.24	64.78	70.15	75.13	79.25	81.34	83.47	85.38	87..64	88.12	89.24	91.20
8	**Veterinary hospital**	16.24	22.14	24.68	29.61	36.52	41.58	47.98	52.95	60.00	66.33	73.25	76.23	81.75	87.09	-	-	-	-	-					
9	**Bus stand**	65.60	75.62	82.95	89.50	94.17	95.98	97.13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	**Post office**	20.25	29.48	35.45	43.06	45.25	50.41	54.68	60.17	63.21	69.25	74.73	80.00	84.56	88.95										
11	**Ware house**	16.24	21.59	23.24	25.74	27.65	30.98	34.65	40.00	44.00	50.21	55.21	60.22	65.24	70.00	76.24	81.34	82.24	83.65	86.32	89.23				

A detailed summary of desirable coverage distance for different facilities from the buffer analysis is presented in Table 4.2.

Table 4.2: Desirable Coverage Distance for Different Facilities

S. no.	Name of Core facility	Name of sub facility	Desirable coverage distance by population coverage (m)
1	Educational facility	Primary school	1000
2		Middle school	3000
3		High school	3000
4		Intermediate/Degree College	8000
5	Medical facility	ANM center	3000
6		PHC center	6500
7		CHC center	8000
8		Veterinary hospital	7000
9	Transport and communication facility	Bus stand	2000
10		Post office	6500
11	Economic activity facility	Ware house	7000

Table 4.3 shows the distribution per 1000 of villages by distance from the nearest general facilities in Andhra Pradesh. This content was taken from the report on village facilities, July-December 2002.

Table 4.3: Distribution per 1000 of villages by distance from the nearest general facilities

S. no.	Facility	Within village	< 2km	2km-5km	5km-10km	>10km
1	Primary school	827		132		39
2	Middle school	456	81	236	31	195
3	High school	237	95	297	94	276
4	Pre University	45	17	128	233	576
5	ANM center	289	58	289	146	247
6	PHC center	67	32	209	273	418
7	CHC center	46	29	117	206	601
8	Veterinary hospital	231	44	252	174	299
9	Bus stand	648	75	61	102	112
10	Post office	503	65	209	73	148

(Source: Report on village facilities, July-December 2002)

4.4 Identification of Rural Hubs by Estimating Village Facility Index (VFI)

Rural Hubs are centres of activities for marketing of agricultural produce and inputs, servicing of agricultural implements, health, and higher education, postal, banking services etc. In this study, village having the highest VFI value and connected with at least one through route is considered as Rural Hub (PMGSY II 2015). Weighted index method was used to determine the VFI and is explained below.

Weighted Index Method (WIM):

In WIM, a group of villages is considered as a block. The weights and the index are calculated in WIM using the following equation (Garg, 2008);

If I_i is the index of particular function 'f' of i^{th} habitation, then;

$$I_i = \sum_{j=1}^{n} W_j * X_j \qquad (3.1)$$

In this study, the average value of core facility index is calculated based on the modified WIM equation of 3.1.

$$I_i = \left(\sum_{j=1}^{n} W_j * X_j\right) / J \qquad (3.2)$$

Where W_j= weight of j^{th}sub facility = w_j*d_j

w_j = villages having j^{th} sub facility / total number of villages in mandal

x_j = value or availability of j^{th} sub facility in ith habitation

dj = distance factor

n= number j^{th} sub facility

J= number of sub facilities considered in core facility

In this study, if the facility is available inside the village the distance factor is consider as 1, if it is within the DCDF then distance factor is consider as 0.5, if the facility is outside the DCDF and then distance factor is consider as 0.25.

VFI is the summation of all facility indices such as Educational Facility Index (EFI), Medical Facility Index (MFI), Transportation and Communication Facility Index (T&CFI) and Economic Activity Facility Index (EAFI).

The calculation of VFI in Nellikudur mandal, i.e., one of the blocks in the study area is presented in Appendix C. By using the above, the VFI calculated for each habitation in the study area, and rural hubs identified are shown in Table 4.4.

Calculation of VFI for Alair village is explained below

$$VFI=EFI+MFI+T\&CFI+EAFI \qquad (3.3)$$

Here,

$$EFI= (PI+MI+HI+DI)/4 \qquad (3.4)$$

PI = Primary school Index, MI = Middle school Index, HI = High school Index,

DI = Degree college Index

For High school

w_j= weight of high school = (number of villages having high schools)/ total number of villages = 7/118 = 0.059

For Alair village, the high school is with in the village and hence, the distance factor (d_j) is considered as 1.

Availability of high schools (x_j) in Alair village is = 1

HI= 0.059*1*1= 0.059

Similarly the indices for other educational sub facilities also calculated and using equation 3.4, the EFI of Alair village is estimated.

In the same manner, other core facility indices i.e. MFI, T&CFI and EAFI are calculated and using equation 3.3, the VFI is estimated for each village.

Table 4.4: Identified rural hubs for each block

S. No	Mandal Name	Rural Hub 1	Rural Hub 2
1	Atmakur	Atmakur	Peddapur
2	Bachannapet	Bachannapet	Padamati keshapur
3	Bhupalapally	Bhupalapally	Azam nagar
4	chytial	chytial	Jookal
5	Cheriyal	Cheriyal	Kommuravelli
6	Chennaraopet	Chennaraopet	Gurijala
7	Devurupala	Devurupala	Chinamadur
8	Dharmasagar	Dharmasagar	Pedda pendyala
9	Duggondi	Duggondi	Thoggarai
10	St Ghanpur	St Ghanpur	Chinna pendyala
11	Mulugu Gahanapur	Mulugu Gahanapur	Chelpur
12	Hasanprthy	Bhemaram	Hasanparthy
13	Kesamudram	Kesamudram	Ingurthy
14	Khanapur	Khanapur	Ashok nagar
15	Kodakandla	Kodakandla	Pedda vangera
16	Kuravi	Kuravi	Modugulagudem
17	Maddur	Maddur	Bairanpalle
18	Mahabubabad	Mahabubabad	Amangal
19	Maripeda	Maripeda	Yellampet
20	Mogullapalle	Mogullapalle	Motllapalle
21	Nalaballe	Nalaballe	Relukunta
22	Narshimulapet	Pedda Mupparam	Narshimulapet
23	Narsampet	Narsampet	Itukalapalle

24	Nellikudur	Nellikudur	Venkatapuram
25	Palakurthy	Palakurthy	Gudur
26	Parkal	Parkal	Charlapali
27	Parvathagiri	Parvathagiri	chintha nekkonda
28	Raiparthy	Raiparthy	Katrepalli
29	Regonda	Regonda	Kothha Pallegori
30	Sangem	Sangem	Gavicherla
31	Shayampet	Shayampet	Koppula
32	Wardanapet	Wardanapet	Inolu
33	Eturu Nagaram	Eturu Nagaram	Chelpaka
34	Tadvai	Tadvai	Naralapuram
35	Govindaraopet	Govindaraopet	Pasaranagarm
36	Gudur	Gudur	Bhupathipet
37	Kothaguda	Kothaguda	Pogullapalle
38	Lingala Ghanpur	Lingala Ghanpur	Nellutla
39	Narmetta	Narmetta	Hanmumanthapur
40	Mangapet	Kamalapur	Mangapet
41	Mulugu	Mulugu	Mallampelli
42	Nekkonda	Nekkonda	Redlawada
43	Dornakal	Dornakal	Chilkodu
44	Thorur	Thorur	Haripriyala
45	Ragunath Pally	Ragunath Pally	Kommala
46	Zaffergadh	Zaffergadh	Uppugal
47	Geesukonda	Dharmaram	Geesukonda
48	Venkatapur	Venkatapur	Peddapur

Two Rural hubs are identified for each mandal. Most of the mandals are having high VFI value of their own headquarters as prior rural hub1. Very few mandals are noticed as rural hub1 other than its headquarters because of more facilities present. For example, Bheemaram is identified as rural hub 1 in Hasanparthy mandal because of education and medical facilities. The identified rural hubs in Warangal district are shown in Figure 4.19.

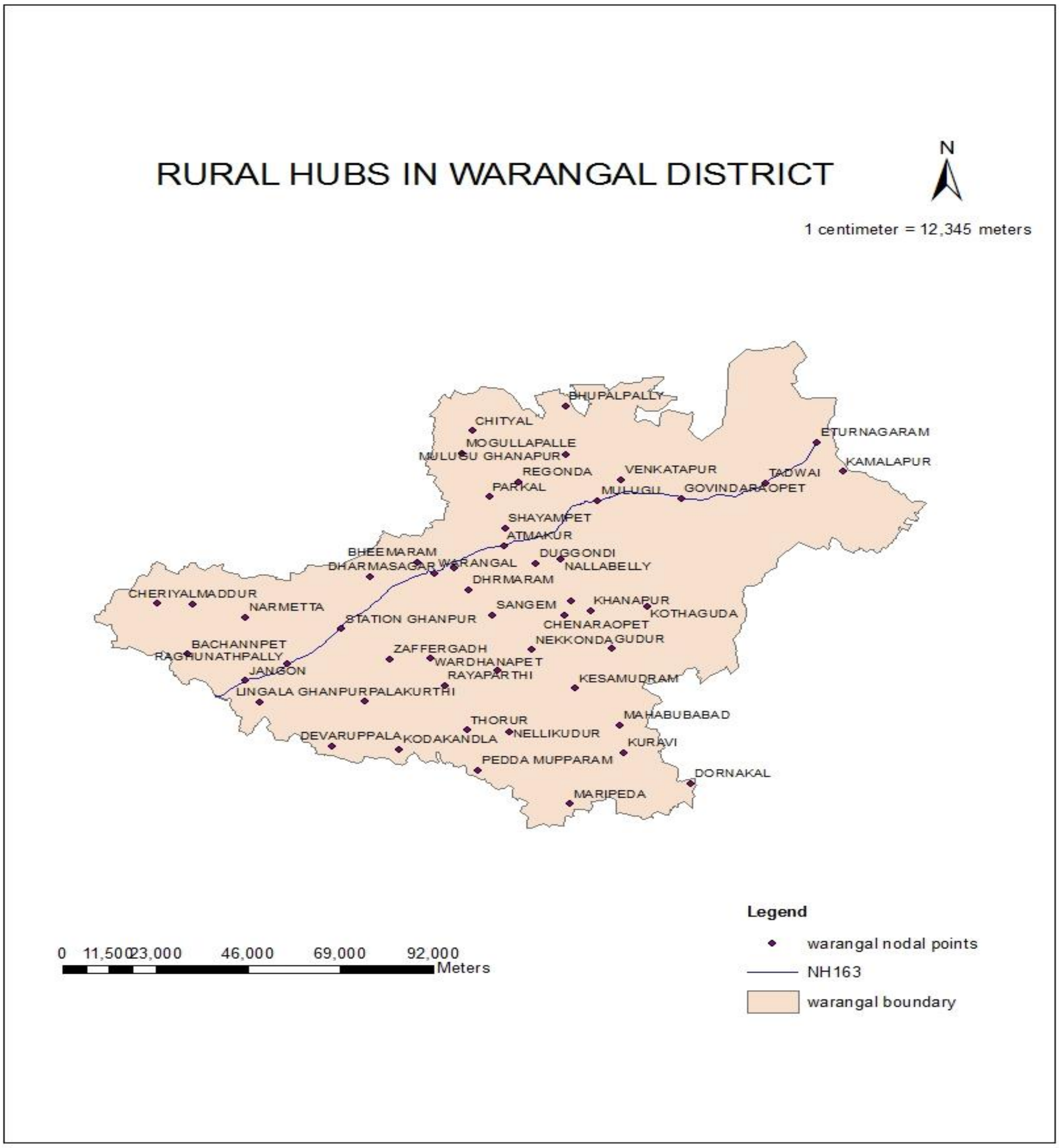

Figure: 4.19 Rural hubs in Warangal district

4.5 Summary

Buffer analysis was performed for all sub-facilities of different core facilities such as educational, medical, transportation, communication and market facilities. Spatial analysis was performed for population coverage approach. Primary school and bus stand facilities having the almost same coverage for all buffer distance was selected. Except for these facilities, almost all facilities show different coverage pattern at same buffer distance. Maximum coverage distance is the same for almost all facility except high school, PHC center and Petrol outlet facility.

Chapter 5

OPTIMAL RURAL ROAD NETWORK

5.1 General

Efficient rural transportation depends largely on a well-knit road network to provide accessibility and mobility in rural areas. The planning of rural road networks at district level is done by focusing on defining the road network that most effectively connects all the identified rural hubs. The aim of rural road network planning should be to connect the most number of settlements possible. Therefore, a minimum connection level where rural hubs cover most of the settlements may be a better approach. Even considering a minimum connection level, often, not all the road links are constructed at the same time due to funding constraints. This chapter focuses on the shortest path analysis and defines the Minimum Spanning Tree (MST) of a network, which represents the optimal network. This analysis is done in order to select the shortest, in terms of travel time between two locations connected through the existing road network. In the present study, travel time was measured by travelling along the road.

5.2 Shortest path analysis

Shortest path problems are the most fundamental and commonly encountered problems in the study of transportation and communication network (Syslo et al., 1983 as cited by Darquah et al. 2007). There are many types of shortest path problems like most economic path or fastest path or minimum fuel consumption path etc. The network analyst gives the user the ability to produce a map and direction for the quickest route among several locations.

Network Analyst calculates the optimal route by means of Dijkstra's Algorithm. The flow chart for carrying out the shortest path analysis is shown in Figure 5.1.

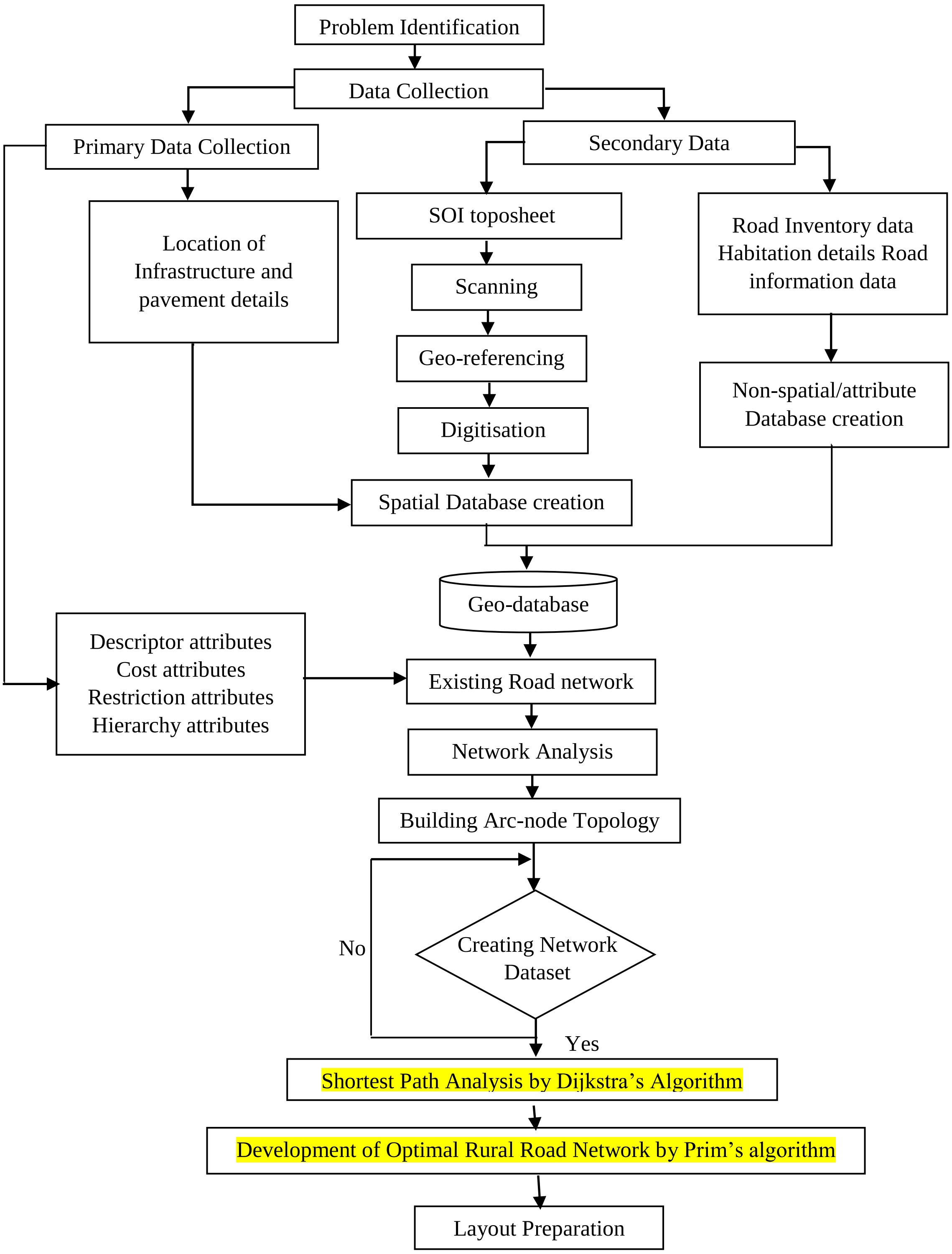

Figure 5.1: Flow chart for network analysis in Arc GIS

5.2.1 Dijkstra’s Algorithm

Dijkstra's Algorithm (DA) is an algorithm for finding the shortest paths between nodes in a network, which may represent, for example, road networks. The algorithm exists in many variants; Dijkstra's original variant found the shortest path between two nodes, but a more common variant fixes a single node as the source node and finds shortest paths from the source to all other nodes in the network, producing a shortest-path tree. For a given source node in the network, the algorithm finds the shortest path between that node and every other node. It can also be used for finding the shortest paths from a single node to a single destination node by stopping the algorithm once the shortest path to the destination node has been determined. For example, if the nodes of the network represent cities and edge path costs represent driving distances between pairs of cities connected by a direct road, Dijkstra's algorithm can be used to find the shortest route between one city and all other cities. The general principle of DA is explained in Appendix G.

5.2.2 Minimum travel path analysis using GIS

To develop the database for the road network, mainly four types of attribute data were collected. First data set are descriptor attributes, which give the description like name of road, road class and speed. Second data set are the cost attributes, play an essential role in the analysis of road network to find the best route, which has the cost of length of road in meters and cost of drive time in minutes. Third data set are the restriction attributes, which also have the main role accompanying cost attributes. This attribute data includes restriction value like one-way, U-turns and others. Fourth data set, hierarchy attributes, which identify the type of roads, and give their hierarchy from primary to local roads to perform network analysis. These attributes are collected directly from field as well as from secondary sources.

In the present study, travel time was measured from the field by travelling along the road using design vehicle. In a place where the terrain is not flat and the level difference between the two origin-destination points is very high, travel time was considered in both directions. In this study, since the terrain is plain and traffic volumes in both directions are more or less equal, the travel times in both directions are assumed to be same. From field survey, it is found that there is no one-way and U-turn restricted link in the study area.

5.2.3 Application to the Hasanparthy mandal in Warangal district

The minimum travel path analysis carried out for a mandal is presented here. Hasanparthy block is considered as a case study for this analysis as shown in Figure 5.2. The shortest and alternative paths towards Rural Hubs were identified using Dijkstra algorithm. The extension tool called network analyst is used to find the shortest path within the given network. Certain locations were selected to find the optimal routes from origin (habitations) of travel to the destination (market centers, rural facilities). From these certain optimal routes, fastest route or shortest route might be selected.

The overall attributes used for network analysis in this study are displayed in Figure 5.2. The attributes include total length of the link, nodes, connectivity (F_Node and T_Node), road name, average speed in miles per second (mps), travel time in both direction (FT_Minutes and TF_Minutes), road classification or category, hierarchy, elevation at each node. In the present study, the elevation of each node is taken as zero (0) because the surface is more or less plain. The collected non-spatial data was mapped into the attribute table of road network and the database has been developed. Discrete, turn table (Appendix-D) was created on Excel and converted to feature class. Figure 5.3 shows the attributes used for the analysis. The developed network dataset for the analysis is shown in figure 5.4.

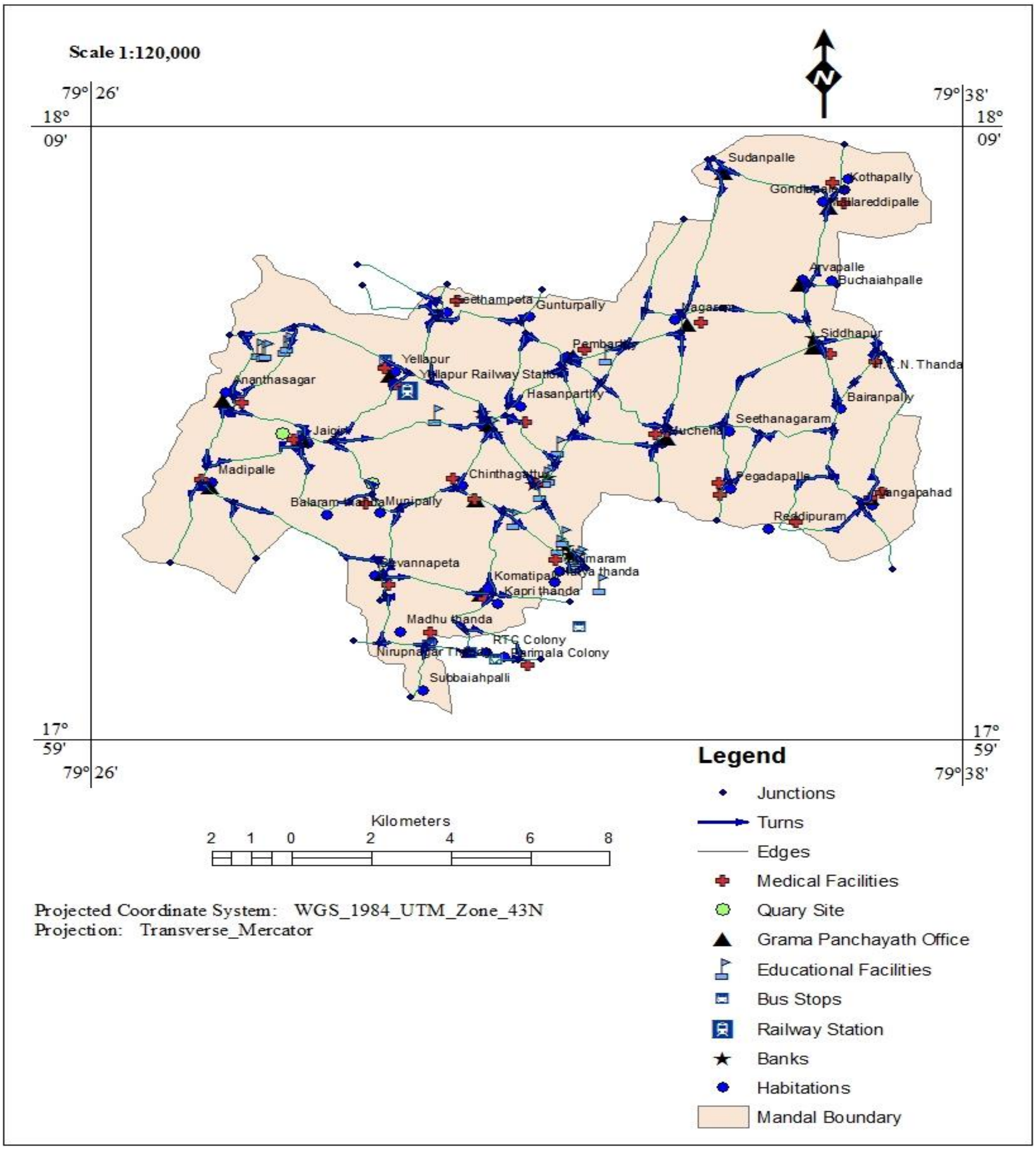

Figure 5.2: Study area considered for minimum travel path analysis

The developed road network database was tested for errors by topology rules. After removing connectivity and other spatial errors, network dataset was built by combining turn table feature class and road network feature class. To this end, network analysis was performed to find the shortest path towards growth centers, public facilities, transport facilities, and medical facilities from different habitations located in the study area.

Attributes of Road_network

Shape	ROAD_	ROAD_NET	FNODE_	TNODE_	HASANPAR	ROAD_NAME	SPEED_KMPH	SPEED_MPS	FT_MINUTES	TF_MINUTES	ROAD_CLASS	HIERARCHY	F_ELEV	T_ELEV	Shape_Leng
Polyline M	1	1	95	94	1	Filterbed to Unikicherla limits	15	4.16667	5.80785	5.80785	Local	1	0	0	1451.962894
Polyline M	2	2	95	93	2	Filterbed to Unikicherla limits	15	4.16667	2.12076	2.12076	Local	1	0	0	530.189792
Polyline M	3	3	91	96	4	PR Road Nirupnagar to Subbaiahpalli	25	6.94444	3.98749	3.98749	Local	1	0	0	1661.452393
Polyline M	4	4	91	92	5	Filterbed to Unikicherla limits	15	4.16667	4.25953	4.25953	Local	1	0	0	1064.882101
Polyline M	5	5	90	91	6	Filterbed to Unikicherla limits	15	4.16667	4.63569	4.63569	Local	1	0	0	1158.921857
Polyline M	6	6	89	90	7	Filterbed to Unikicherla limits	15	4.16667	2.6118	2.6118	Local	1	0	0	652.948861
Polyline M	7	7	92	88	8	Filterbed to Komatipaly via Banjara colony	25	6.94444	1.65094	1.65094	Local	1	0	0	687.892789
Polyline M	8	8	95	88	9	Parimala colony to Komatipaly via Banjara colony	25	6.94444	4.60365	4.60365	Local	1	0	0	1918.188852
Polyline M	9	9	85	86	10	Unikicherla Road to Devannapet road via Maduthand	15	4.16667	1.12112	1.12112	Local	1	0	0	280.279817
Polyline M	10	10	85	90	11	Unikicherla Road to Devannapet via Madu thanda	15	4.16667	5.90379	5.90379	Local	1	0	0	1475.947375
Polyline M	11	11	88	84	12	IMVR04 X to Komatipaly via Banjara colony	25	6.94444	4.35262	4.35262	Local	1	0	0	1813.590079
Polyline M	12	12	87	84	13	Devannapet to Hanamkonda via Kapri Thanda	25	6.94444	4.6562	4.6562	Local	1	0	0	1940.083836
Polyline M	13	13	83	85	14	Unikicherla Road to Devannapet road via Maduthand	25	6.94444	1.43008	1.43008	Local	1	0	0	595.865873
Polyline M	14	14	84	83	15	Devannapet to Hanamkonda via Kapri Thanda	25	6.94444	6.87669	6.87669	Local	1	0	0	2865.286836
Polyline M	15	15	81	80	16	Rayapatnam to Kodad	35	9.72222	0.147916	0.147916	Secondary	2	0	0	86.284554
Polyline M	16	16	83	78	17	Devannapet to Madipally	15	4.16667	1.79097	1.79097	Local	1	0	0	447.742211
Polyline M	17	17	84	74	18	Chinthagattu to Komatipally	15	4.16667	10.593	10.593	Local	1	0	0	2648.258083
Polyline M	18	18	74	80	19	PWD Road Bheemaram to Anathasagar via Munipally	25	6.94444	6.95984	6.95984	Local	1	0	0	2899.932278
Polyline M	19	19	78	72	20	Devannapet to Munipally	15	4.16667	8.16409	8.16409	Local	1	0	0	2041.021754
Polyline M	20	21	82	71	22	Arepally to Kantatmakur road KM0/0 to 16/085	35	9.72222	3.49703	3.49703	Local	1	0	0	2039.932738
Polyline M	21	22	74	70	23	Chinthagattu to SH7@125/2	25	6.94444	2.81407	2.81407	Local	1	0	0	1172.52919
Polyline M	22	23	80	70	24	Rayapatnam to Kodad	35	9.72222	3.55011	3.55011	Secondary	2	0	0	2070.897563
Polyline M	23	24	71	69	25	Arepally to Kantatmakur road KM0/0 to 16/085	35	9.72222	0.254638	0.254638	Local	1	0	0	148.538982
Polyline M	24	25	68	77	26	Madipally to Repaka X road	25	6.94444	4.43718	4.43718	Local	1	0	0	1848.826922
Polyline M	25	26	78	68	27	Devannapet to Madipally	15	4.16667	16.4368	16.4368	Local	1	0	0	4109.19783
Polyline M	26	28	66	72	29	PWD Road Bheemaram to Anathasagar via Munipally	25	6.94444	2.30504	2.30504	Local	1	0	0	960.434202
Polyline M	27	29	65	74	30	PWD Road Bheemaram to Anathasagar via Munipally	25	6.94444	3.32538	3.32538	Local	1	0	0	1385.575181
Polyline M	28	30	72	65	31	PWD Road Bheemaram to Anathasagar via Munipally	25	6.94444	3.91146	3.91146	Local	1	0	0	1629.775855
Polyline M	29	31	70	64	32	Rayapatnam to Kodad	35	9.72222	1.08597	1.08597	Secondary	2	0	0	633.484593
Polyline M	30	32	63	68	33	Madipally to Repaka X road	25	6.94444	2.38707	2.38707	Local	1	0	0	994.614098
Polyline M	31	33	79	63	34	SH7 to Madipally via Ananthasagar	25	6.94444	6.11208	6.11208	Local	1	0	0	2546.701672
Polyline M	32	34	75	62	35	KUC Road to Pegadipally X	25	6.94444	2.85067	2.85067	Local	1	0	0	1187.780991
Polyline M	33	35	69	61	36	Arepally to Kantatmakur road KM0/0 to 16/085	35	9.72222	1.90371	1.90371	Local	1	0	0	1110.49821
Polyline M	34	36	76	61	37	PWD Road to Vangapahad X via Reddipuram	15	4.16667	9.77528	9.77528	Local	1	0	0	4857.200205
Polyline M	35	37	63	60	38	SH7 to Madipally via Ananthasagar	25	6.94444	1.3082	1.3082	Local	1	0	0	545.0846
Polyline M	36	38	64	59	39	Parkal to Erragattugutta	35	9.72222	1.46613	1.46613	Local	1	0	0	855.240397
Polyline M	37	39	67	58	40	University to Mucherla Nagaram Km 0/0 to 9/900	35	9.72222	2.87656	2.87656	Local	1	0	0	1677.991647
Polyline M	38	40	60	57	41	Jayagiri to Madipalle	15	4.16667	10.5092	10.5092	Local	1	0	0	2627.28722
Polyline M	39	41	73	57	42	Balramthanda to Jayagiri	15	4.16667	9.64414	9.64414	Local	1	0	0	3683.986494
Polyline M	40	42	56	66	43	PWD Road Bheemaram to Anathasagar via Munipally	25	6.94444	4.88053	4.88053	Local	1	0	0	2033.554564

Record: 1 Show: All Selected Records (0 out of 117 Selected) Options

Figure 5.3: Data attribute window for carrying the network analysis using Arc GIS

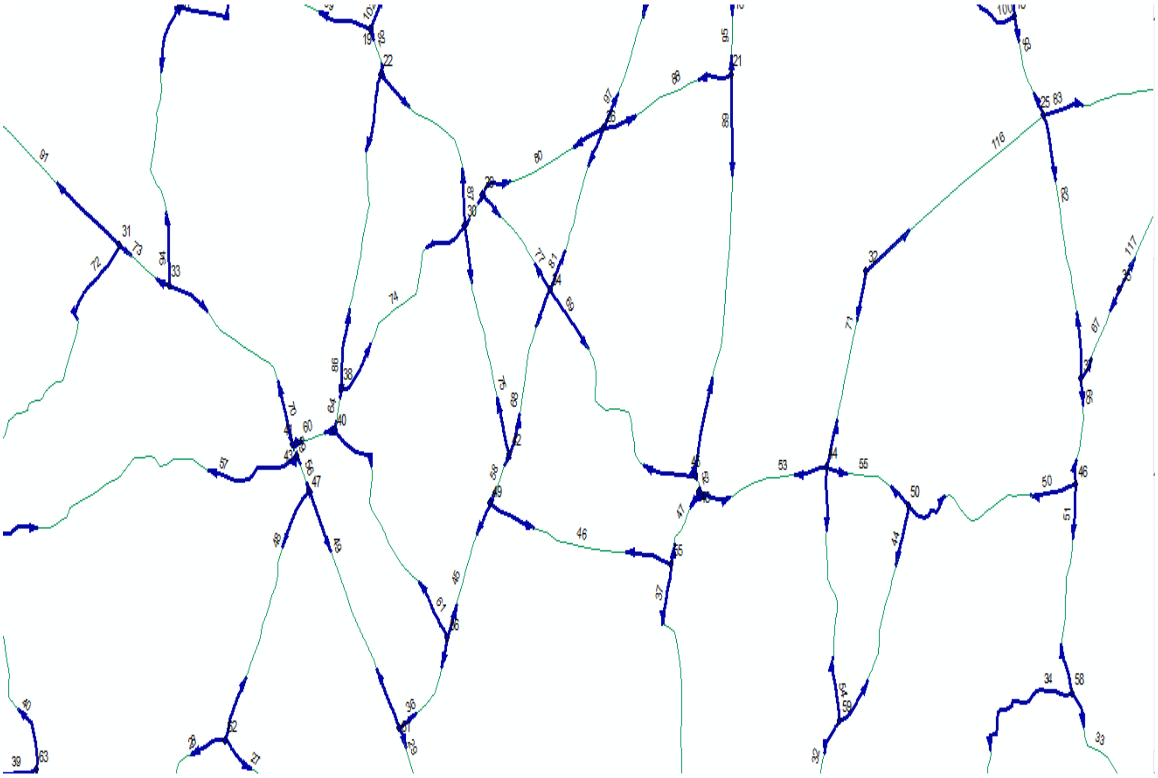

Figure 5.4: Network data set for minimum travel path analysis

The network analysis was carried out in the Hasanparthy mandal using ArcGIS and the results are shown in Figure 5.5

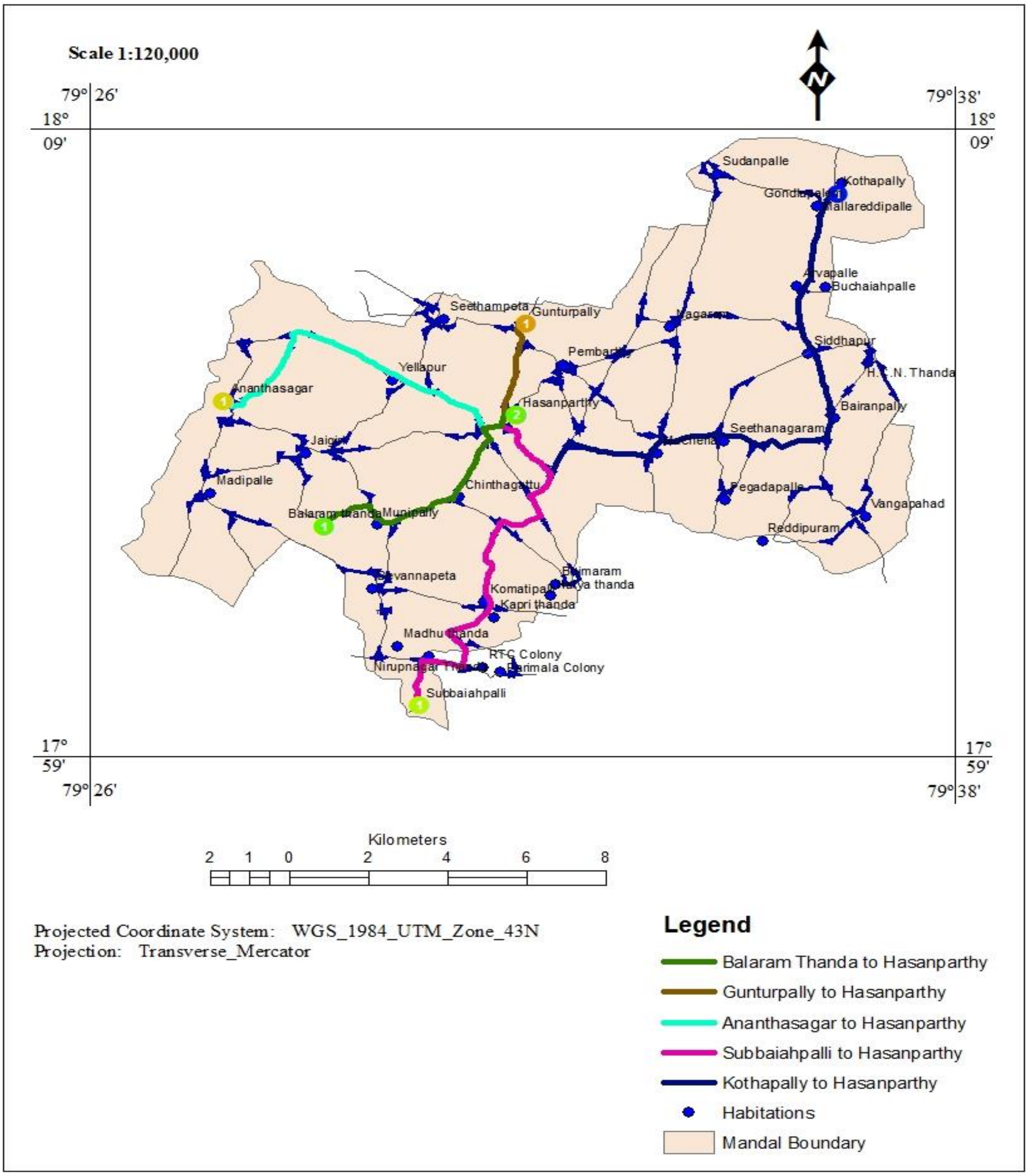

Figure 5.5: Minimum travel path analysis towards rural hub at block level

Similarly, this analysis is enlarged to add different mandals and carry out the minimum travel path analysis and the results are shown in Figure 5.6.

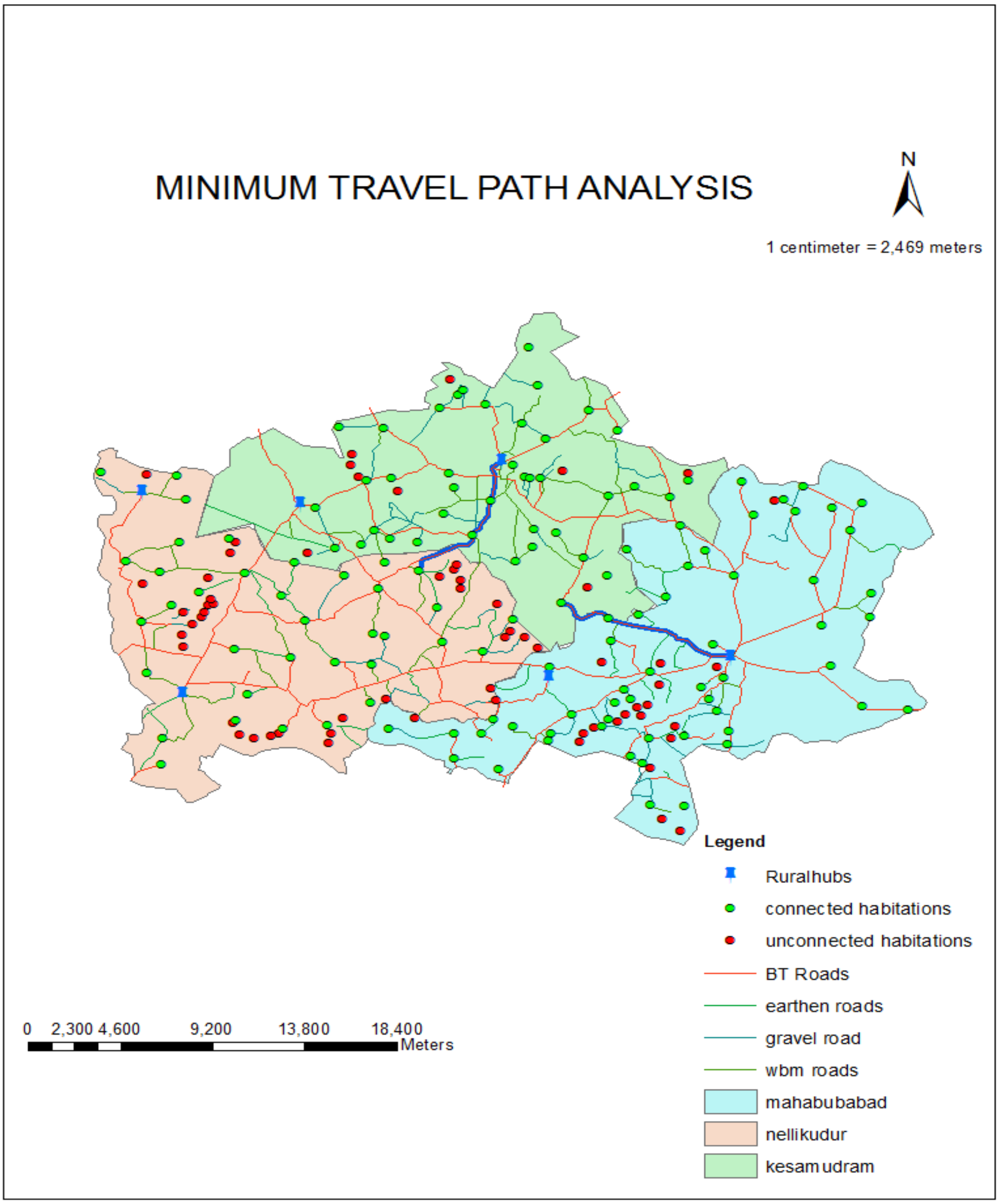

Figure 5.6: Minimum travel path analysis towards rural hubs from different mandal blocks

5.3 Development of Optimal Rural Road Network

In this study, the optimal road network was developed at district level. The connection between the nodal points by the rural road links forms the basic network. A distance matrix connecting all the nodal points and the connecting points in the rural roads network is to be obtained. Afterwards, a Minimum Spanning Tree (MST) can be obtained, using Prim's Algorithm (Prim, 1957). The MST network represents the minimum connection level necessary for the rural accessibility of a specified coverage distance. This MST represents the optimal rural road network, and covers the most of the settlements and public facilities within the region in consideration.

5.3.1 Minimum Spanning Tree (MST)

In graph theory, a tree can be defined as a connected graph G with n vertices and n-1 edges and does not having any sub-tour or loop among the vertices. A spanning tree of a graph (network) is a tree (sub-graph) consisting of all the nodes (vertices) of that graph. MST of a network (graph) is a spanning tree (sub-graph) consisting of all the vertices of the same graph in such a way that the sum of weights of all edges is minimum among all such possible spanning trees of that network.

The standard application of MST is in network design i.e. in telephone networks, TV cable network, computer network, road network, islands connection, pipeline network, electrical circuits, utility circuit printing, obtaining an independent set of circuit equations for an electrical network etc. to keep costs down.

5.3.2 Prim's algorithm

Prim's algorithm was developed by computer scientist Robert Prim in 1957. Prim's Algorithm (see Appendix-B) is a quick way of finding the Minimum Spanning Tree (or minimum connector) of a network (graph). This algorithm starts from an arbitrary node in the network, and builds upon a single partial minimum spanning tree, at each step adding an edge of lowest weight connecting the vertex nearest to but not already in the current partial minimum spanning tree with a condition that the properties of a tree should be maintained (connected sub-graph of n vertices and n-1 edges). It continues until the tree spans all the vertices in the given network. This algorithm is called greedy because at each step the partial spanning tree is augmented with an edge that is the smallest among all possible neighboring edges.

5.3.3 ArcGIS script tool development

In this study customized tool was used to solve MST problem using the Prim's algorithm. For the development of MST, script tool in python (Appendix F) was used. A layer file (.lyr) is being created as shown in Figure 5.7 by using ArcPy Feature Layer Management Tool to display the resultant minimum spanning tree data (Minimum SHAPE_Lengths) on the ArcMap screen.

Next step is to modify the script tool by setting up the parameter functions and index values, so that user can take input directly from the ArcGIS window. An ArcGIS toolbox has been created and the script in then added into it by setting up all the input and output parameters. Parameters in the ArcGIS script tool are the options of giving input and taking output from the python script. After finalizing the process of adding script tool that can run the tool in the ArcMap by taking necessary inputs from the user as shown in figure 5.8.

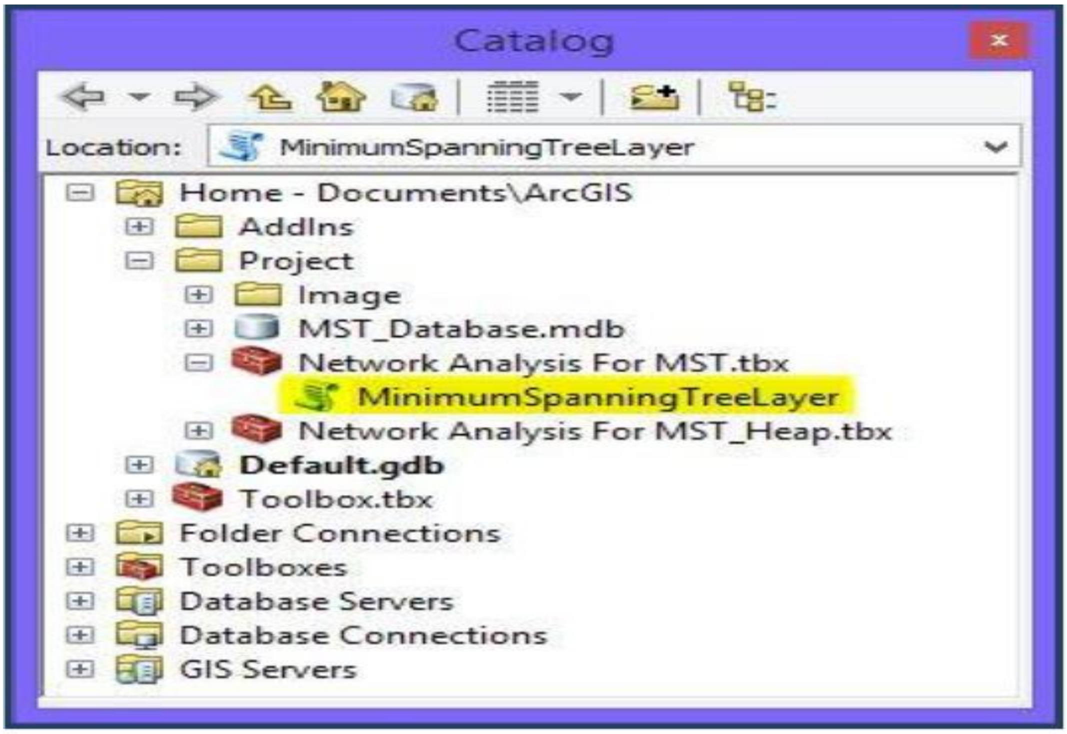

Figure 5.7: MST Toolbox in the catalog

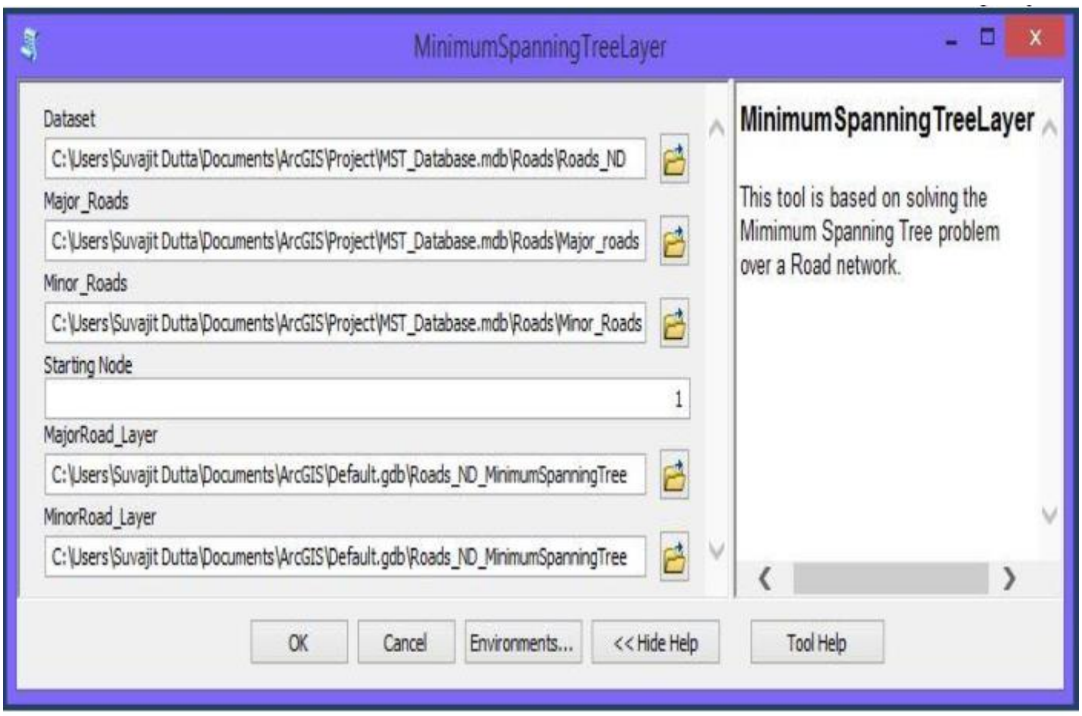

Figure 5.8: User interface of the MST tool considering all necessary inputs

Warangal rural district, which is separated from erstwhile Warangal, was taken as study area and it is shown in Figure 5.9**.** The MST of the network and minimum travel path towards administration centers are shown in Figures 5.10.

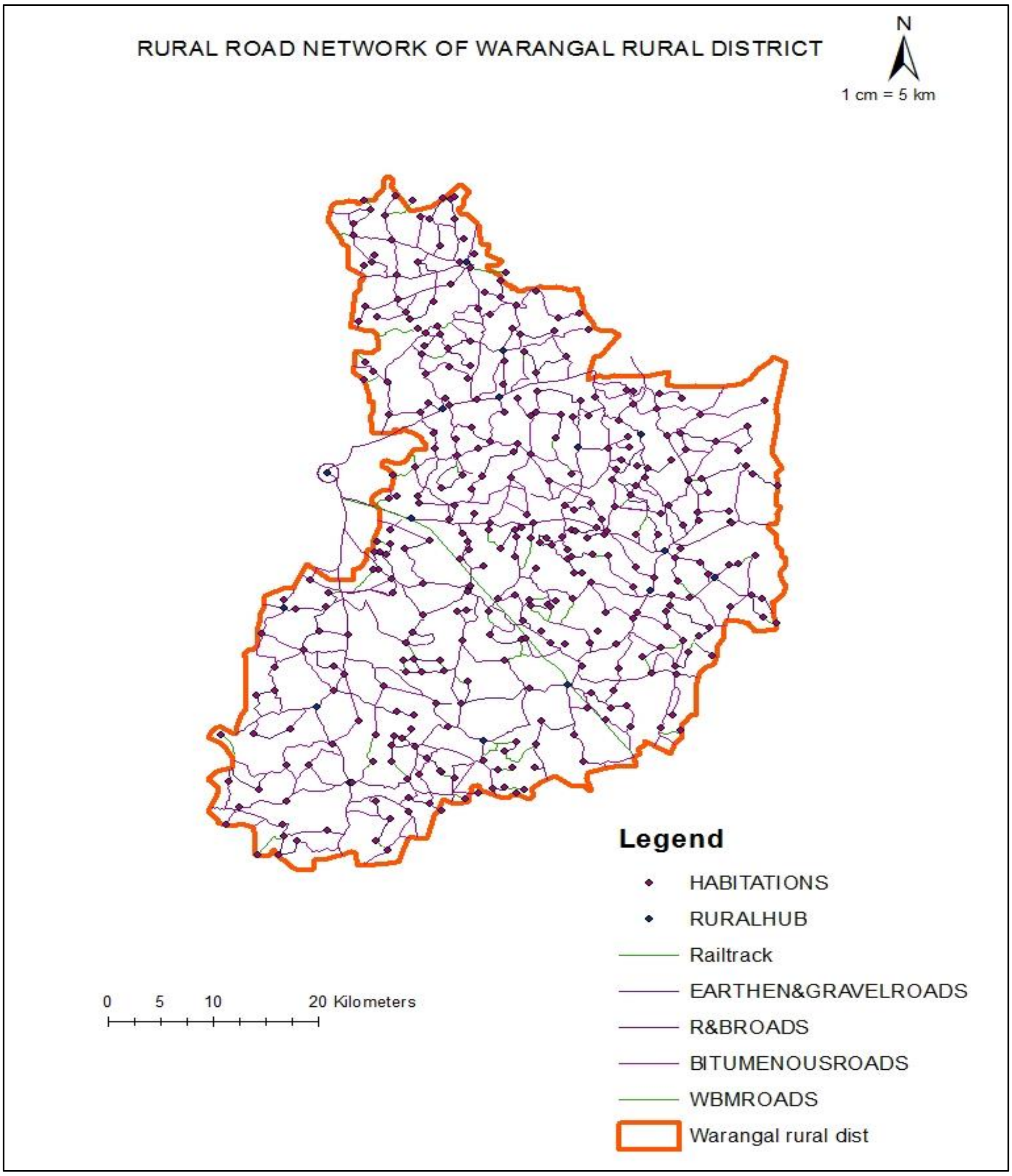

Figure 5.9: Rural road network of Warangal rural district

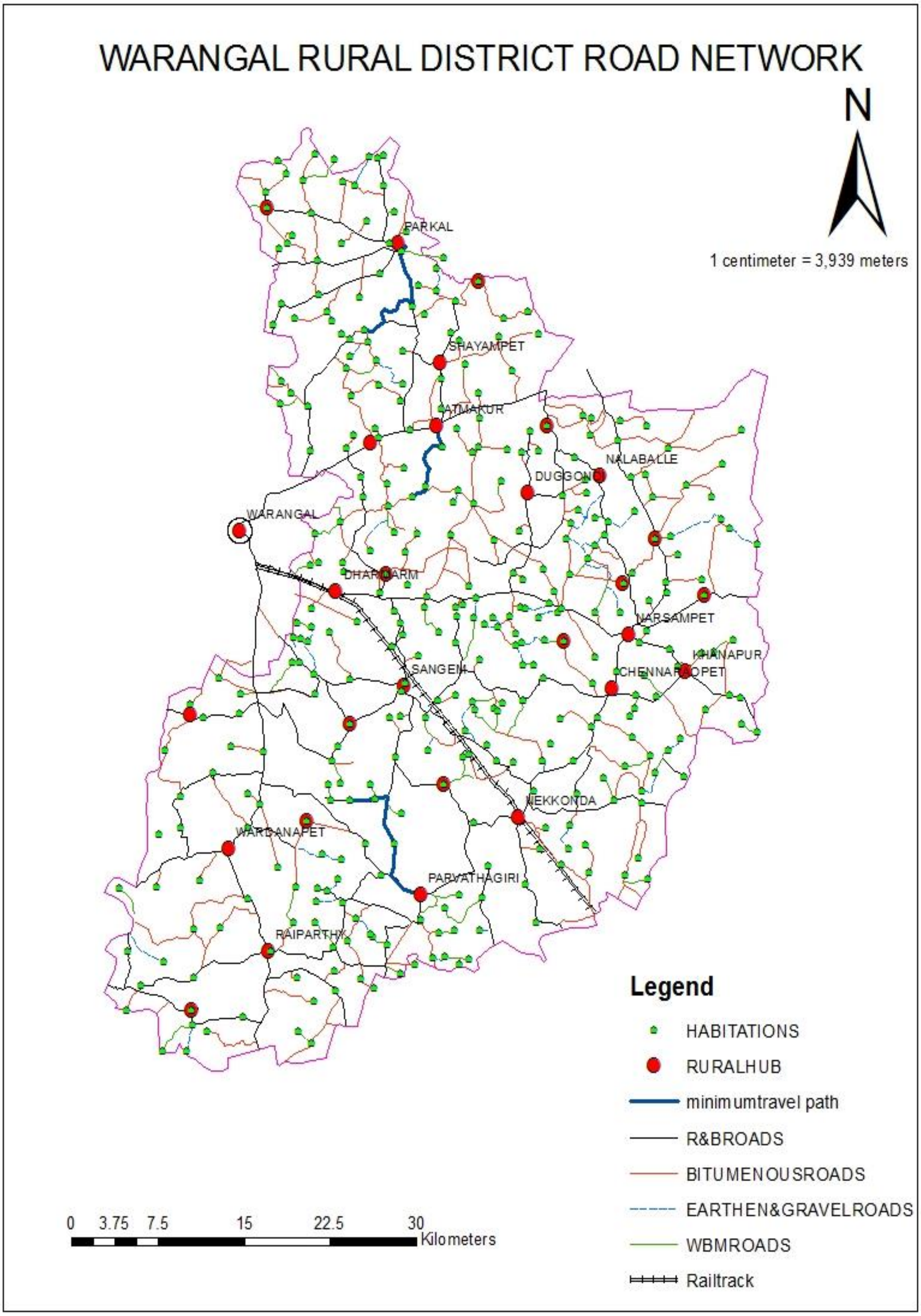

Figure 5.10 MST of Warangal rural road network

The MST is one level of optimization of road network as it has given the road network length significantly less than the existing network ensuring better connectivity of the nodal points and covering settlements and public facilities.

5.4 Summary

Optimal rural road network at district level is defined in this chapter. The network analysis tool ArcGIS is used to perform the minimum travel path analysis. The travel times observed from the field were used in this analysis. This model is useful in identifying the situation of coverage of settlements and public facilities by the rural hubs in different service distances. The pattern was developed in search of best routes to connect the rural settlements and public facilities.

Chapter 6

OPTIMISATION MODELS FOR RURAL ROAD NETWORK

6.1 General

The development of infrastructure such as public facilities and road network extensively studied in the past were mostly independently of each other. It has been realized that these two issues, facility location and rural road network, have a direct impact on each other and should therefore be studied in a comprehensive and integrated manner. Apart from limited financial resources to build rural roads and public facilities, the lack of proper planning methodology of these rural infrastructures is also a major problem (Heng et al., 2006). The models developed for the urban areas are often not suitable for rural areas. Hence, a study on the planning of rural roads and public facility locations in an integrated manner, targeting optimized budget allocation is the main objective of this chapter.

In this study, rural road network models are designed to considering public facility locations to achieve minimum total cost comprising construction and operation cost of the different road surface options (e.g. earthen, gravel, and bituminous).

6.2 Rural Road Network Models

The model to be developed aims to achieve the least total cost. The total cost includes all costs associated with construction/improvement and operation of a road network. The mathematical formulation considers a single surface in new constructions and different road surfaces options like WBM and asphalt in upgrading of links. The model allows investigating the public resource allocation in order to attain minimum total cost. There are two models proposed for rural road networks, which will be discussed as follows.

6.2.1 Rural road network model 1 (RRNM-1): New connection

Links for network connection were observed from both map and field. The objective function of the model can be written to consider connection of the links so that highly potential links are connected based on budget availability. Then, the model can be formulated as follows

Maximise

$$\sum_{i,j \in L} W_{ij} x_{ij} \tag{6.1}$$

Subjected to

$$\sum_{(i,j) \in L} I_{ij}\, x_{ij} \leq B \tag{6.2}$$

$$x_{ij} = 1 \qquad \forall (i,j) \in L \tag{6.3}$$

Where,

W_{ij} is the weight of the link (i,j).

B is an available investment budget.

6.2.2 Rural road network model 2(RRNM-2): Upgrading network

Roads for upgradation works were identified from the field survey. Field surveys were conducted in the study area by traveling along the road with a comfortable riding quality and observed the normal driving speed on the road. In this study, roads for upgradation works were identified based on the pavement condition index (PCI) of a road.

The objective function of the model can be rewritten to consider the operating cost with weights to the links (Shrestha et al., 2012).

Minimise

$$z = \sum_{S=1}^{4} \sum_{(i,j)\in L} C_{ij}^{s}\, x_{ij}^{s} \tag{6.4}$$

The model is rewritten as

$$z = \sum_{S=1}^{4} \sum_{(i,j)\in L} W_{ij} O_{ij}^{s}\, x_{ij}^{s} \tag{6.5}$$

Subjected to

$$\sum_{S=1}^{4} \sum_{(i,j)\in L} I_{ij}^{s}\, x_{ij}^{s} \le B \tag{6.6}$$

$$\sum_{S=1}^{4} x_{ij}^{s} = 1 \qquad \forall (i,j) \in L,\ \forall s \in S \tag{6.7}$$

$$x_{ij}^{s} \in \{0,1\} \qquad \forall (i,j) \in L \quad \forall s \in S \tag{6.8}$$

Where,

S is the type of upgraded road surface options S= {s1, s2, s3, s4} for new bituminous, upgraded bituminous, new WBM, upgraded WBM respectively.

W_{ij} is the weight of the link (i,j).

$C^s_{ij}$is the travel cost per unit flow over surface type $s \in S$ on link (i,j).

d_{ij} is the distance from node i to node j.

c^s_{ij} is the operating cost per unit flow of traveling over surface type s on link(i,j).

O^s_{ij} is the operating cost on link (i,j) over surface type $s \in S$, where $O^s_{ij} = d_{ij}c^s_{ij}$.

B is an available investment budget, and $I^s{}_{ij}$ s the cost of improving link (i,j) with surface type. The decision variables in this model are: x_{ij}=1 if a link (i,j) is to be built with surface type s, 0 otherwise. For new construction, S will have a single surface; hence, notation "s" is not needed.

The objective function (6.5) considers the minimization of the weighted user operating cost aiming to obtain economic efficiency. Constraint (6.6) ensures that Upgradation expenditure is constrained to an investment budget. Constraint (6.7) ensures that one link is to be paved with only one type of surface.

6.3 Multi-Criteria Prioritization of Links

Fund available for rural road construction/upgrade is usually a constraint in developing countries. Hence, the available resources should be effectively used. For this, a prioritisation method is necessary. Based on a realistic and practical criterion, the rural road links in the network are to be prioritised.

There are many methods for prioritisation of road links. They are usually based on economic returns from the road linkages. The traditional feasibility indicators for economic evaluation of highway are Net Present Value (NPV), discounted Benefit Cost (B/C) ratio, and Internal Rate of Return (IRR). These conventional methods are used for urban, and highways and higher standard roads where the economic return can be fairly estimated. The conventional economic indicator may therefore not be suitable for rural roads. Moreover, there is significant difficulty in quantifying the economic benefits and return from rural roads. Hence, a different approach is necessary to categorise and prioritise the road links in a rural road network.

6.3.1 Identify the Links for Network Connection and Upgradation

To identify the roads to be upgraded, field surveys were conducted in the study area by traveling along the road in a design vehicle with a comfortable riding quality and the normal driving speed on the road. Identification of roads for up gradation was based on the PCI of a road. PCI values are indexed on a scale from 1 to 5 as shown in Table 6.1, where ‘1’ shows worst possible condition and ‘5’ shows the best possible condition of the pavement (PMGSY II Manual).

Table 6.1: Assessment of PCI based on comfortable normal driving speed of the vehicle

PCI	Normal Driving Speed	Road Condition
5	Over 40 kmph	Very Good
4	30-40 kmph	Good
3	20-30 kmph	Fair
2	10-20 kmph	Poor
1	< 10 kmph	Very Poor

In the present study, comfortable speed of the vehicle was observed from the field surveys by traveling on each road twice in a year, i.e., before and after the rainy season in both the direction. The details of links for network connection and for upgradation work observed from field survey are presented in Tables 6.2 and 6.3 and a detailed map is shown in Figure 6.1.

Table 6.2: Details of road links for new network connection

Link number	Road name	Population served	Expected length (km)
L052	Errabally Gudem to Chowkunta Thanda	136	1.5
L056	Machirajupally to Padamati Thanda	581	1
L025	PR road to Pedda Thanda	353	3
L054	PR road to Rama Chilakala Goodu Thanda	48	1
L033	PWD road to Vasram Thanda	577	1
L066	PWD Road to Balunaik thanda	287	1.93
L065	Narsimhulagudem to Sandhya thanda	267	2
L064	Bodlada to Tejya thanda	78	2

Table 6.3: Details of road links for upgradation work

Road Number	Road Name	Total Population served	Existing surface
L053	Erraballigudem to Varam Banda Thanda	603	EARTHEN
L055	Kachikal to Thimma Thanda	309	WBM
L027	Narsimhulagudem to Dharavath Bheemala Thanda	267	EARTHEN
L028	Narsimhulagudem to Nandya Thanda	173	BT
L049	PR road to Badavath Lakpathi Thanda	512	EARTHEN
L023	PR road to Goplapuram	92	EARTHEN

L050	PR road to Kothur Thanda	393	WBM
L021	PR Road to Narayanapuram	736	WBM
L044	PR road to Suryanayak Thanda Thanda	124	EARTHEN
L043	PR road to Tulasya Thanda	232	EARTHEN
L041	PWD road to Hemala Thanda	351	EARTHEN
L061	PWD Road to Bojya thanda	380	WBM
L039	PWD road to Laxmipuram	323	WBM
L063	PWD Road to Metya thanda	198	EARTHEN
L060	Rathiram Thanda to Nalla Gutta Thanda	476	EARTHEN
L057	Chinnanagaram to Seetharampuram	786	WBM
L062	Chinnanagaram to Jama thanda	943	EARTHEN
L022	Rajulakothapally to Venkatapuram	384	WBM
L034	PWD road to Bojya Peenya Thanda	154	EARTHEN
L031	PWD road to Panthulu thanda Via Munigalaveedu	2913	WBM
L051	PR road to Baduva thanda	287	EARTHEN
L046	Vavilala to Rajya Thanda	552	EARTHEN
L047	PR road to Hemla Thanda	80	EARTHEN
L032	PWD road to Madanthurty	1609	WBM

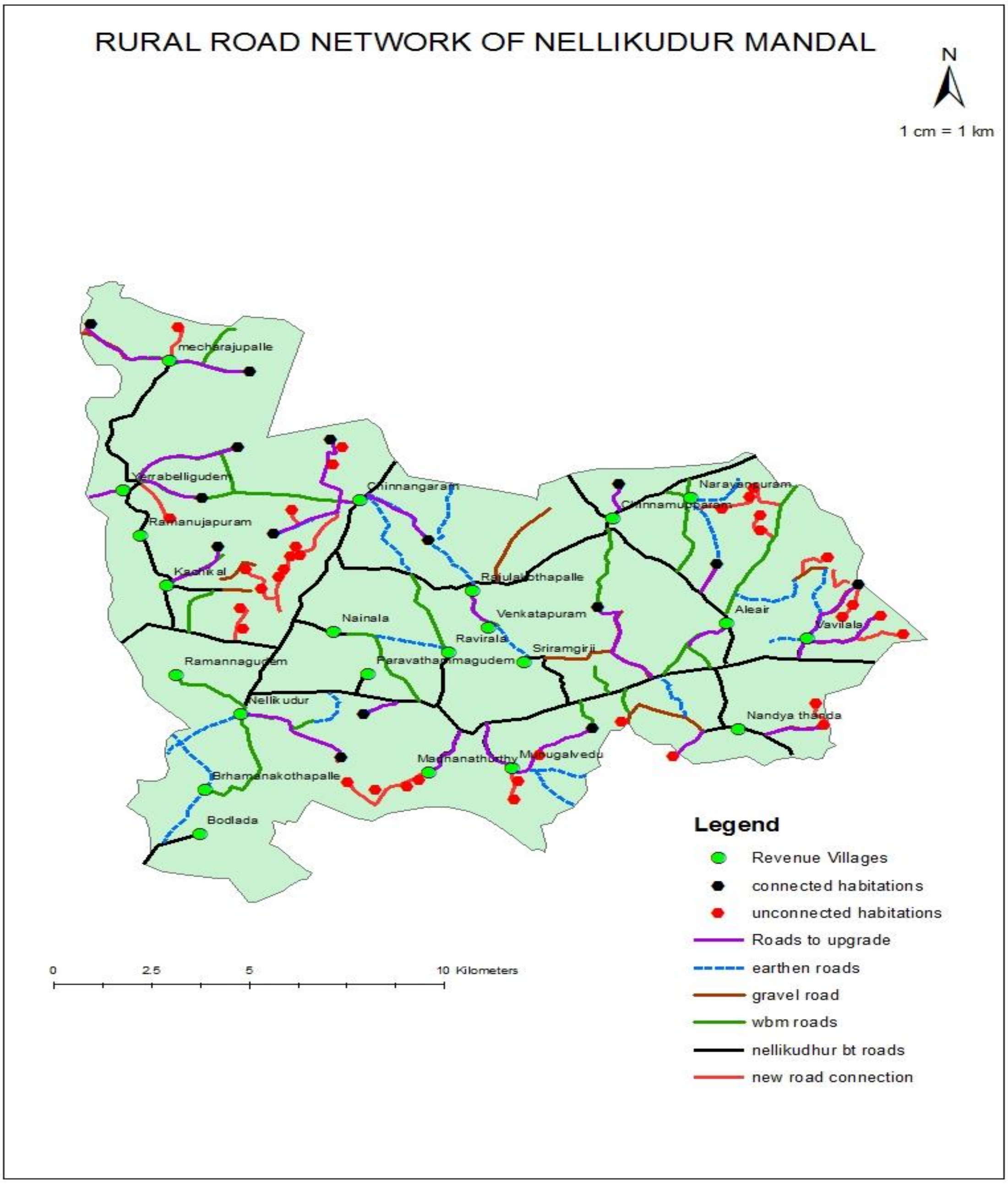

Figure 6.1: Identified links for upgradation and new connection in Nellikudur mandal

6.3.2 Indicators for Rural Road Evaluation

Road links are generally prioritized based on economic analysis. The methodology is based on a system for estimating future traffic on improved roads based on readily available data.

Two scenarios can be found: one for roads under operation (passable), and the other for impassable roads. The impassable roads can be of two categories. The first category can be the new construction and the second is when the road is in poor condition. For impassable roads, lowest costs per head links were ranked highest. Here the problem is to quantify the number of trips in the links. There can be different trips such as district, agricultural and fishery trips.

An alternative method is necessary to prioritize the road links in the network primarily based on social factors. The key social factor in the rural area is the population covered by a road link. Traffic generation in rural road links are due to population. Hence, calculation of priority factor based on the population covered by links can be a realistic approach. The weight assigned based on population can be as comparable as trip generation in a link.

The construction costs can be taken as proportional to the lengths of links. Hence, link lengths have been taken as a proxy for construction costs (Kumar and Tillotson, 1985). Similarly, travel costs can be taken as proportional to a factor called "person-km", is defined as the product of population connected by the village node to its root node and the distance between that village node and its root node (Kumar and Tillotson, 1985).

The travel costs are likely to be proportional to (i) the number of people connected by the link, and (ii) the distance travelled through the link to reach the destination. It is therefore argued that whatever the travel costs, they will be proportional to a factor called 'person-km' (Makarchi & Tillotson, 1991) which is defined as the product of population connected by the link, and the distance between the village and the destination through the link.

The model proposed by Kumar and Kumar, (1999) chooses the construction standards for a link on the basis of the population served by the link. Population is considered as a good proxy for traffic in rural areas because traffic data generally is difficult to get. Road links can be ordered according to the population served and then road surface type for each category.

For prioritisation of rural roads, generally two broad approaches are used: (a) sufficiency rating and (b) cost-benefit analysis. The cost benefits method analyses various costs and benefits associated with a road which have to be evaluated in the same monetary terms, and therefore a difficult task. The model uses a simple parameter, that is, the population served with unit investment, for prioritisation of rural roads. As mentioned earlier, accessibility to people is considered as a benefit of the investment in rural roads.

In this study planning for prioritization of links is achieved by considering two different-approaches.

i. Population considered as proxy
ii. Vulnerability analysis

6.3.3 Population considered as proxy

Prioritisation of links is necessary to implement a connection in a network for both types of links either new or upgrading of the existing network. The parameters considered in this approach are given below.

i. Population served by links (P1)
ii. Person-km (P2)
iii. Population served/km (P3)

The weightages calculated from above parameters for new connection links and for upgradation links are presented in Tables 6.4 and 6.5 respectively.

6.3.4 Vulnerability of link (P4)

A vulnerability of the link was considered as link weight. Taylor et al. (2006) proposed the evaluation index based on accessibility of a node. Hansen integral accessibility index is given below.

$$A_i = \sum B_j f(C_{ij}) \quad (6.10)$$

Where,

A_i accessibility index for a location i.

$B_j$is attractiveness of location j, in this research B_j has been taken as facility index value of location j.

f (c_{ij})is an impedance function calculated as a reciprocal of the distance between i and j (1/x_{ij}).

Accessibility index of a node was calculated for two different scenarios i.e. at normal condition and possible failure of each link one at a time. The vulnerability is calculated by change in accessibility after failure of a link. The critical link is that link which has the higher change in accessibility in a locality at the time of failure assumption. The vulnerability calculation of a link is presented in Appendix F.

Table 6.4: Weightages based on population, person-km, population per unit construction cost

Road Number	Road Name	Total Population Served P1	Population served-km P2	Population served/km P3	% population served	% cumulative p-km	% population served/km
L052	Errabally Gudem to Chowkunta Thanda	136	204	91	1.06	0.61	1.61
L056	Machirajupally to Padamati Thanda	581	581	581	4.51	1.75	10.29
L025	PR road to Pedda Thanda	353	1,059	118	2.74	3.18	2.08
L054	PR road to Rama Chilakala Goodu Thanda	48	48	48	0.37	0.14	0.85
L033	PWD road to Vasram Thanda	577	577	577	4.48	1.73	10.22
L066	PWD Road to Balunaik thanda (VR51)	287	554	149	2.23	1.67	2.63
L065	Narsimhulagudem to Sandhya thanda (VR50)	267	534	134	2.07	1.61	2.36
L064	Bodlada to Tejya thanda	78	156	39	0.61	0.47	0.69

Table 6.5: Link weightages consider for upgradation work

S.No.	Road Number	Road Name	Total Population Served P1	Population served-km P2	Population served/km P3	% population served	% cumulative p-km	% population served/km
1	L053	Erraballigudem to Varam Banda Thanda	603	1206	301.50	4.68	3.63	5.34
2	L055	Kachikal to Thimma Thanda	309	618	154.50	2.40	1.86	2.74
3	L027	Narsimhulagudem to Dharavath Bheemala Thanda	267	667.5	106.80	2.07	2.01	1.89
4	L028	Narsimhulagudem to Nandya Thanda	173	346	86.50	1.34	1.04	1.53
5	L049	PR road to Badavath Lakpathi Thanda	512	1536	170.67	3.98	4.62	3.02
6	L023	PR road to Goplapuram	92	184	46.00	0.71	0.55	0.81
7	L050	PR road to Kothur Thanda	393	786	196.50	3.05	2.36	3.48
8	L021	PR Road to narayanapuram	736	1104	490.67	5.72	3.32	8.69
9	L044	PR road to Suryanayak Thanda Thanda	124	248	62.00	0.96	0.75	1.10
10	L043	PR road to Tulasya Thanda	232	232	232.00	1.80	0.70	4.11

11	L041	PWD road to Hemala Thanda	351	702	175.50	2.73	2.11	3.11
12	L061	PWD Road to Bojya thanda	380	380	380.00	2.95	1.14	6.73
13	L039	PWD road to Laxmipuram	323	969	107.67	2.51	2.91	1.91
14	L063	PWD Road to Metya thanda	198	396	99.00	1.54	1.19	1.75
15	L060	Rathiram Thanda to Nalla Gutta Thanda	476	952	238.00	3.70	2.86	4.21
16	L057	Chinnanagaram to Seetharampuram	786	2043.6	302.31	6.10	6.14	5.35
17	L062	Chinnanagaram to Jama thanda	943	2357.5	377.20	7.32	7.09	6.68
18	L022	Rajulakothapally to Venkatapuram	384	960	153.60	2.98	2.89	2.72
19	L034	PWD road to Bojya Peenya Thanda	154	308	77.00	1.20	0.93	1.36
20	L031	PWD road to Panthulu thanda Via Munigalaveedu	2913	11652	728.25	22.62	35.03	12.90
21	L051	PR road to Baduva thanda	287	861	95.67	2.23	2.59	1.69
22	L046	Vavilala to Rajya Thanda	552	1380	220.80	4.29	4.15	3.91
23	L047	PR road to Hemla Thanda	80	160	40.00	0.62	0.48	0.71
24	L032	PWD road to Madanthurty	1609	3218	804.50	12.50	9.67	14.25

6.4 Application of Models and validation

Nellikudur mandal was considered as case study for this analysis. This mandal has 54.62 % connectivity level and lowest connectivity of road network in erstwhile Warangal district.

From the calculation of link weights, the priority list for new connections and Upgradation work is presented in Tables 6.6 and 6.7 respectively.

Table 6.6: Priority list for new connection

S.No	Road Name	Link Number	Population served by link (P1)	Persons served-km (P2)	Persons served/km (P3)	Vulnerability analyis (P4)
1	Errabally Gudem to Chowkunta Thanda	L052	6	6	6	4
2	Machirajupally to Padamati Thanda	L056	1	2	1	3
3	PR road to Pedda Thanda	L025	3	1	5	2
4	PR road to Rama Chilakala Goodu Thanda	L054	8	8	7	8
5	PWD road to Vasram Thanda	L033	2	3	2	6
6	PWD Road to Balunaik thanda	L066	4	4	3	1
7	Narsimhulagudem to Sandhya thanda	L065	5	5	4	5
8	Bodlada to Tejya thanda	L064	7	7	8	1

Table 6.7: Priority list for Upgradation work

S.No	Road Name	Link Number	population served by link (P1)	persons served-km (P2)	persons served/km (P3)	vulnerability analysis (P4)
1	Erraballigudem to Varam Banda Thanda	L053	6	8	6	17
2	Kachikal to Thimma Thanda	L055	12	13	8	5
3	Narsimhulagudem to Dharavath Bheemala Thanda	L027	17	16	19	14
4	Narsimhulagudem to Nandya Thanda	L028	16	17	17	2
5	PR road to Badavath Lakpathi Thanda	L049	10	6	14	8
6	PR road to Goplapuram	L023	22	22	23	22
7	PR road to Kothur Thanda	L050	7	10	7	6
8	PR Road to Narayanapuram	L021	5	12	5	21
9	PR road to Suryanayak Thanda Thanda	L044	20	19	20	7
10	PR road to Tulasya Thanda	L043	24	24	21	11
11	PWD road to Hemala Thanda	L041	14	14	13	24
12	PWD Road to Bojya thanda	L061	18	21	10	16

13	PWD road to Laxmipuram	L039	9	5	12	3
14	PWD Road to Metya thanda	L063	21	20	22	10
15	Rathiram Thanda to Nalla Gutta Thanda	L060	15	15	15	11
16	Chinnanagaram to Seetharampuram	L057	3	3	4	4
17	Chinnanagaram to Jama thanda	L062	4	4	3	23
18	Rajulakothapally to Venkatapuram	L022	8	7	9	19
19	PWD road to Bojya Peenya Thanda	L034	19	18	18	20
20	PWD road to Panthulu thanda Via Munigalaveedu	L031	1	1	1	9
21	PR road to Baduva thanda	L051	13	11	16	15
22	Vavilala to Rajya Thanda	L046	11	9	11	13
23	PR road to Hemla Thanda	L047	23	23	24	18
24	PWD road to Madanthurty	L032	2	2	2	1

The roads upgraded with different surface options and the construction cost per kilometer for upgradation work are presented in Table 6.8.

Table 6.8: Surface options with approximate costs

S.No.	Existing Surface Type	Upgraded surface type	Pipe Culvert per unit (INR Lakhs)	Causeway per unit (INR Lakhs)	Approximate Construction Cost - per km. (INR Lakhs) excluding CD works
1	WBM	New BT (NBT1)	2.0	30.0	50.0
2	BT	Upgraded BT (UBT)	2.0	30.0	18.0
3	Gravel	New WBM	2.0	30.0	15.0
4	EARTHEN	New WBM (NWBM)	2.0	30.0	30.0

The construction cost of earthen road for new connections is approximately 10 lakhs per kilometer. The construction cost per km was considered from the line estimation from Standard Bidding Document 2016-17 and from OMMAS for PMGSY. The analysis is conducted at different budget levels. The methods of prioritisation have been applied in each model. The interventions in the network link at the different budget levels are shown in Tables 6.9 to 6.16.

Table 6.9: Intervention in the network link at different budget levels based on P1 (RRNM1)

Budget Availability (INR Lakhs)/Link No.	L056	L033	L025	L066	L065	L052	L064	L054
15	P	N	N	N	N	N	N	N
30	P	P	N	N	N	N	N	N
45	P	P	N	P	N	N	N	N
60	P	P	P	N	N	N	N	N
75	P	P	P	P	N	N	N	N
90	P	P	P	P	P	N	N	N
105	P	P	P	P	P	P	N	N
120	P	P	P	P	P	P	N	P
135	P	P	P	P	P	P	P	P

Table 6.10: Intervention in the network link at different budget levels based on P2 (RRNM1)

Budget Availability (INR Lakhs)/Link No.	L025	L056	L033	L066	L065	L052	L064	L054
30	P	N	N	N	N	N	N	N
45	P	P	N	N	N	N	N	N
60	P	P	P	N	N	N	N	N
75	P	P	P	P	N	N	N	N
90	P	P	P	P	P	N	N	N
105	P	P	P	P	P	P	N	N
120	P	P	P	P	P	P	N	P
135	P	P	P	P	P	P	P	P

Table 6.11: Intervention in the network link at different budget levels based on P3 (RRNM1)

Budget Availability (INR Lakhs)/Link No.	L056	L033	L066	L065	L025	L052	L054	L064
15	P	N	N	N	N	N	N	N
30	P	P	N	N	N	N	N	N
45	P	P	P	N	N	N	N	N
60	P	P	P	P	N	N	N	N
75	P	P	P	P	N	P	N	N
90	P	P	P	P	P	N	N	N
105	P	P	P	P	P	P	N	N
120	P	P	P	P	P	P	P	N
135	P	P	P	P	P	P	P	P

Table 6.12: Intervention in the network link at different budget levels based on vulnerability analysis (RRNM1)

Budget Availability (INR Lakhs)/Link No.	L066	L064	L025	L056	L052	L065	L033	L054
15	P	N	N	N	N	N	N	N
30	P	N	N	P	N	N	N	N
45	P	P	N	N	N	N	N	N
60	P	P	N	P	N	N	P	N
75	P	P	P	N	N	N	N	N
90	P	P	P	P	N	N	P	N
105	P	P	P	P	P	N	P	N
120	P	P	P	P	P	P	N	N
135	P	P	P	P	P	P	P	P

P= Possible for upgradation with in the budge, N= Not possible for upgradation with in the budget

Table 6.13: Intervention in the network link at different budget levels based on P1 (RRNM-2)

Budget Availability (INR Lakhs)	Link number																							
	L31	**L32**	**L57**	**L62**	**L21**	**L53**	**L50**	**L22**	**L39**	**L49**	**L46**	**L55**	**L51**	**L41**	**L60**	**L28**	**L27**	**L061**	**L34**	**L044**	**L063**	**L023**	**L047**	**L043**
200	P	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
400	P	P	N	P	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
600	P	P	P	P	P	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
800	P	P	P	P	P	P	P	N	N	N	N	N	N	N	N	N	N	P	N	N	N	N	N	N
1000	P	P	P	P	P	P	P	P	N	P	N	N	N	N	N	N	N	N	N	N	N	N	N	P
1200	P	P	P	P	P	P	P	P	P	P	P	N	N	N	N	N	N	N	N	N	N	N	N	N
1400	P	P	P	P	P	P	P	P	P	P	P	P	P	N	N	N	N	N	N	N	N	N	N	N
1600	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	N	N	N	N	N	N	N	P
1800	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	N	N	N	N	P
2000	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	N
2200	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P

Table 6.14: Intervention in the network link at different budget levels based on P2 (RRNM-2)

Budget Availability (INR Lakhs)	**Link number**																							
	L31	**L32**	**L057**	**L062**	**L021**	**L053**	**L050**	**L022**	**L039**	**L049**	**L046**	**L055**	**L051**	**L041**	**L060**	**L028**	**L027**	**L061**	**L034**	**L044**	**L063**	**L023**	**L047**	**L043**
200	P	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
400	P	P	N	P	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
600	P	P	P	P	N	P	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
800	P	P	P	P	P	P	N	N	N	N	N	N	N	N	N	N	N	N	N	N	P	N	N	N
1000	P	P	P	P	P	P	P	P	N	N	N	N	N	P	N	N	N	N	N	N	N	N	N	N
1200	P	P	P	P	P	P	P	P	P	P	N	P	N	N	N	N	N	N	N	N	N	N	N	N
1400	P	P	P	P	P	P	P	P	P	P	P	P	P	N	N	N	N	N	N	N	N	N	N	N
1600	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	N	N	N	N	N	N	N	N
1800	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	N	N	N	N	P
2000	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	N
2200	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P

Table 6.15: Intervention in the network link at different budget levels based on P3 (RRNM-2)

Budget Availability (INR Lakhs)	**Link number**																							
	L031	**L032**	**L062**	**L057**	**L021**	**L053**	**L050**	**L055**	**L022**	**L061**	**L046**	**L039**	**L041**	**L049**	**L060**	**L051**	**L028**	**L034**	**L027**	**L044**	**L043**	**L063**	**L023**	**L047**
200	P	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
400	P	P	P	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
600	P	P	P	P	P	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
800	P	P	P	P	P	P	P	N	N	P	N	N	N	N	N	N	N	N	N	N	N	N	N	N
1000	P	P	P	P	P	P	P	P	P	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
1200	P	P	P	P	P	P	P	P	P	P	P	N	P	N	N	N	P	N	N	N	N	N	N	N
1400	P	P	P	P	P	P	P	P	P	P	P	P	P	P	N	N	N	N	N	N	N	N	N	N
1600	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	N	N	N	N	N	N	N
1800	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	N	N	N	N
2000	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P

Table 6.16: Intervention in the network link at different budget levels based on vulnerability (RRNM-2)

Budget Availability (INR Lakhs)	Link number																							
	L031	L032	L057	L062	L021	L053	L050	L022	L039	L049	L046	L055	L051	L041	L060	L028	L027	L061	L034	L044	L063	L023	L047	L043
200	P	P	N	N	N	N	P	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
400	P	P	P	N	P	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
600	P	P	P	P	P	N	P	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
800	P	P	P	P	P	P	P	P	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
1000	P	P	P	P	P	P	P	P	P	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
1200	P	P	P	P	P	P	P	P	P	P	P	P	P	N	N	N	N	N	N	N	N	N	N	N
1400	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	N	N	N	N	N	N	N	N	N
1600	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	N	P	N	N	N	N
1800	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	N	N	N
2000	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P

As per the availability of the budget, the decision maker can select a set of links for intervention. The output of three methods P1, P2, and P3 are somehow similar. All the methods have population served as the key parameter. In rural areas, the accessibility problem is the main and then others. Hence, the vulnerability analysis method can be more realistic for prioritisation of new networks. The third method P3 takes into account the population and the cost of construction (indirectly by taking distance) and may be a realistic parameter for prioritisation of upgrading of rural roads.

6.5 Summary

The important indicators for prioritisation of rural road links identified are population served by a road link, person–km, population per unit intervention cost, and vulnerability of link. Hence, consideration of a few significant indicators makes the process more simple, practical, and possibly sufficient for the rural roads prioritisation.

In this chapter, the problem of designing a rural transportation network to provide better accessibility to public services/ facilities for the rural residents around the network along with cost-effective road improvement was explained. The proposed models provide suggested links for road network improvements, and offer solutions for different budget levels, optimizing the transportation cost in a rural road network with different types of road surface (earthen, gravel, or asphalt).

Chapter 7
SUMMARY AND CONCLUSIONS

7.1 Summary

Rural areas have sparsely located settlements and public facilities. The delivery of services and goods to the settlements is therefore a difficult task for local governments of developing countries. Connecting every settlement in rural area is not possible in practice due to financial constraints. However, settlements in remote areas should have access basic goods and services, even though connectivity of all settlements in rural areas is not feasible. Hence, the network problem was dealt with in terms of covering of settlements and public facilities within a specified distance. A method was developed to identify the rural hubs in rural road network so that most settlements can be covered.

Spatial analysis of the facility in the study area helps the organization to understand the influence of the facility of maximum habitations/population covered from the facility and useful for facility allocation problems.

Buffer analysis was carried out for ten selected mandals for all sub facilities of different core facilities, such as educational, medical, transportation and communication and market facilities. Spatial analysis is performed for population coverage approach. Desirable coverage distances for various facilities in the study are presented in Table 7.1. (Reproduced from Table 4.2.)

It is observed that accessible levels of these facilities are good in the study area. There is a need to identify a suitable location for providing public facilities like PHC center, cold storage, community health centers, and banks.

Table 7.1: Desirable coverage distance for different facilities

S. no.	Name of facility	Desirable coverage distance by population coverage (m)
1	Primary school	1000
2	Middle school	3000
3	High school	3000
4	Intermediate/Degree College	8000
5	ANM center	3000
6	PHC center	6500
7	CHC center	8000
8	Veterinary hospital	7000
9	Bus stand	2000
10	Post office	6500
11	Petrol outlet	7000

A two-step method was found effective to define rural road network. In the first step, rural hubs were identified based on the VFI and connecting with the through routes in a region. These rural hubs were taken as obligatory points in a rural road network. Then, in the second step, the model established the linkages to the rural hubs to form a basic road network in the specified region.

The MST of road network connecting the rural hubs identified was used as a basic rural road network for the study as shown in figure 7.1 (Reproduced from Figure 5.10). This network has been taken as the minimum level of connectivity/coverage necessary for the study.

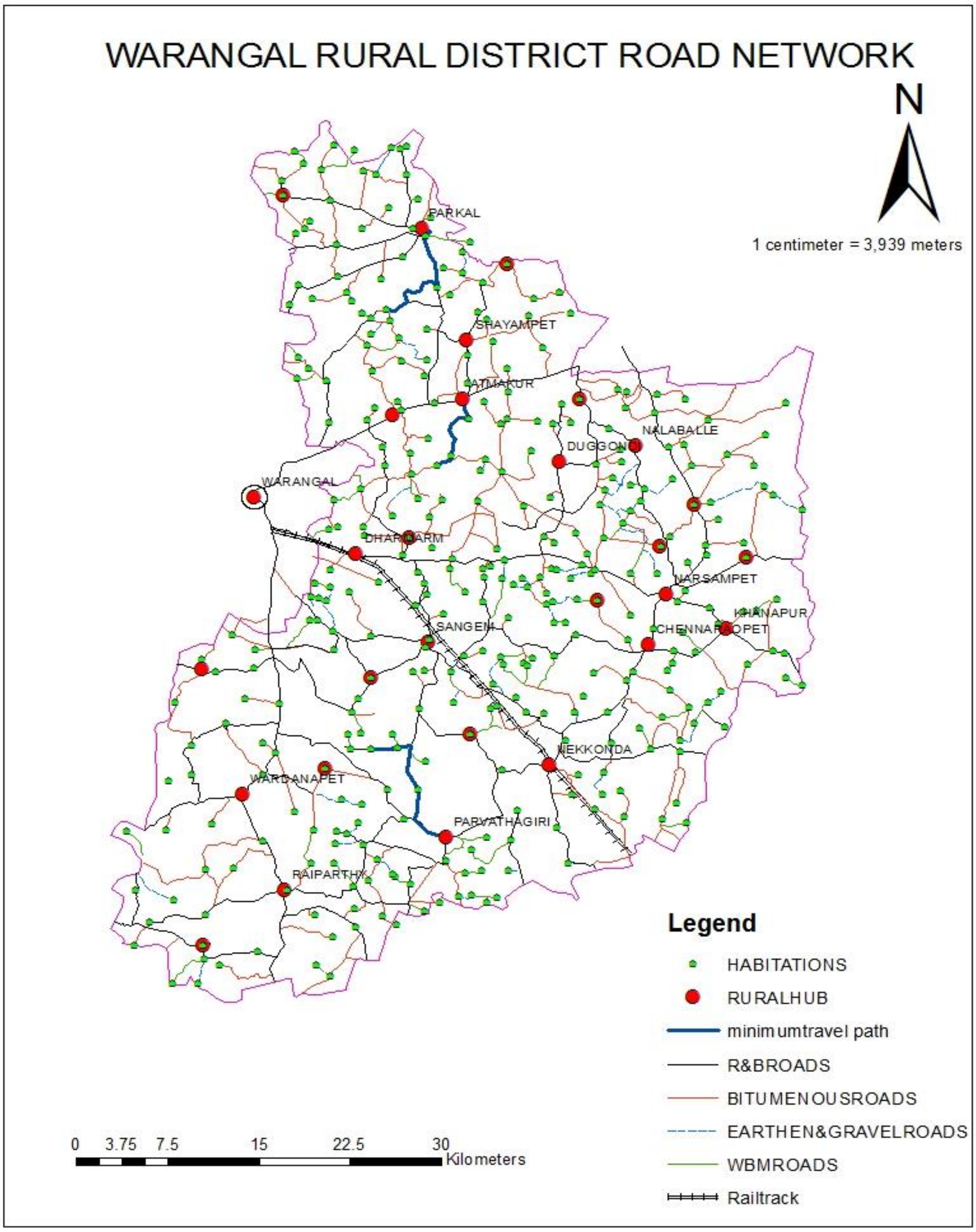

Figure 7.1: MST of Warangal rural road network

Optimal rural road network at block level and district level was defined. The network analysis tool in ArcGIS was used to perform the minimum travel path analysis. The travel times observed from the field were used in this analysis. This model is useful in identifying the situation of coverage of settlements and public facilities by the nodal points in different service distances. The concept of minimum travel path analysis can be applied for emergency cases, service area allocation and facility allocation.

Two models were found appropriate for the rural road network in rural areas and proposed as rural road network decision models. The relevant indicators for prioritisation of rural road links are also identified as population served by a road link, person–km, population per unit intervention cost, and vulnerability of the link.

The models provided a portfolio of suggested links for road network improvements, and offered solutions for different budget levels optimizing the transportation cost in a rural road network with different types of road surface (earthen, gravel, or asphalt) for upgrading and new connections. Typical analysis carried out for Nellikudur mandal is presented in Table 7.2. (Reproduced from Table 6.9).

Table 7.2: Intervention in the network link at different budget levels

Budget Availability (INR Lakhs)/Link No.	**L056**	**L033**	**L025**	**L066**	**L065**	**L052**	**L064**	**L054**
15	P	N	N	N	N	N	N	N
30	P	P	N	N	N	N	N	N
45	P	P	N	P	N	N	N	N
60	P	P	P	N	N	N	N	N
75	P	P	P	P	N	N	N	N
90	P	P	P	P	P	N	N	N
105	P	P	P	P	P	P	N	N
120	P	P	P	P	P	P	N	P
135	P	P	P	P	P	P	P	P

As per the availability of the budget, the decision maker can select a set of links for intervention. Rural road organizations can use this model effectively for planning and management of the roads.

7.2 Conclusions

The following are the important conclusions drawn from the research work:

1. Spatial analysis of the facility in the study area helps the organization to understand the influence of the facility and is useful for facility allocation problems.

2. The proposed method can be a practical and realistic approach for identifying rural hubs or growth centers in rural areas.

3. Optimal rural road network at block level and district level was developed by minimum travel path analysis. This optimal network has been taken as the minimum level of connectivity.

4. The concept of minimum travel time path analysis is adopted to avail the emergency services and general facility allocation with a constrained budget.

5. Vulnerability is an essential factor in distribution networks, particularly in the rural areas. This approach, which considers critical links is a more realistic one for prioritization of Upgradation works in a given rural road network.

6. The proposed optimisation model can be used effectively for planning and maintenance management of the rural roads.

7. It is easier for authorities or decision maker to select a set of links for intervention with available budget.

7.3 Limitations

Some limitations were identified during the development of the work presented in this thesis, which will be enumerated as follows and may be useful for future consideration.

1. The current condition of the road was examined based on comfortable driving speed possible and the decision was taken by personal judgment, which is subjective.
2. Line estimates (cost per km) are considered, rather than detailed estimates for up-gradation of each work.

7.4 Scope for future study

Encountered limitations and ideas led to consider some future work and to identify promising research directions as follows

1. Identifying the overall impact of rural road investment including estimating benefits that go beyond transport cost savings.

2. Selection of rural road for prioritization based on its potentials of generating economic and social activities in the area.

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APPENDIX A

Transportation Division

Department of Civil Engineering

National Institute of Technology, Warangal

RURAL ROAD INVENTORY DATA COLLECTION FORMAT

Section-I:

1. Name of the road:____
2. From:________________________ To:__________________________________
3. Length of the road (km):_____________________ Speed(km/hr):____________________
4. Type of road:___________________________ Travel Time(sec):____________________
5. Terrain (Plain/Rolling/Hilly):______________________________________
6. Road link number:_____________________________Mandal:___________________________
7. Year of last construction: ____________________Funding Source:____________________
8. Construction agency (contractors firm):____
9. Maintenance agency:________________________ Last maintenance:_________________
10. Connected Habitations details

S.No	Name	Population	Chainage	Directly/Indirectly Connected	Remark
1					
2					
3					
4					
5					
6					
7					
8					

11. Traffic volume (AADT):________________________________(Vehicles/day)
    Modal Share:
    2W:_____________3W:__________________Cars/Jeep: ______________LCV:______________
    Buses: ____________ Trucks: ________________ Track Trailors: ___________________
    Non-motorized Transport (Cycles/Animal drawn Vehicles):__________________
12. Accident History
    Accident type: ________________________ Year: ____

Severity: ____________________________ Accident Prone Area: _________________________

Section-II: Details of Pavement and its Condition

1. Chainage of the road:_________________________
2. Pavement Details
   i. Type:________________________________
   ii. Width (m):___________________________
   iii. Total Thickness (mm):_________________
   iv. Composition:
      a) Wearing Course/Slab thickness (mm):______________________
      b) Base Course (mm):________________________
      c) Subbase Course (mm):_____________________
3. Subgrade type/dominating soil type:_______________________
4. Shoulder Details

Shoulder	Type	Length (m)	Condition(P/F/G)	Remark
Left				
Right				

5. Pavement Condition Index (PCI):______________________
6. No. of Horizontal Curves:____________________________
7. No. of Vertical Curves:______________________________
8. No. of carriageways:_________________________ FT/TF/N:____________________
9. Restricted Vehicle types:____

10. Existing Railway Crossing details

S.No	Chainage	Type	Location	Remark

11. Existing CD Details

S.No	Chainage	Type	Length (m)	Width/diameter (m)	Condition(P/F/G)

APPENDIX B

A brief description of the Prim's Algorithm (Prim, 1957) is described below.

At first a peak is chosen in random order ,which for simplicity we accept it as $V_{(1)}$.This way two sets of pointers are initialized, the $O=\{1\}$ and $P=\{2...n\}$. The O set will always contain the pointers of those peaks which are terminally attached in the T tree. The $V_{(1)}$ peak has already been attached in the T tree. The P set contains the rest of the pointers for the peaks, $P=\{1...n\}-O$ which are those pointers who have not been terminally connected with a node of T, that means they are not attached in the tree.

In every execution of the Prim Algorithm, a new peak will be connected to the T tree, not always with their numbering order, for example the $V_{(4)}$ peak can be connected to the tree before the $V_{(2)}$ peak. The corresponding pointer of the newly connected peak will be deleted from P set and will be inserted to the O set. When all peaks are connected there will be $O= \{1,...n\}$ and $P=0$. This means the end of the algorithm.

The new peak every time will be chosen by using greedy method, among all sides of G which connect peaks already inserted in the T (pointers in the O set) tree with the rest of the peaks (pointers in the P set), we choose one with minimum cost. If the chosen one is $e_{(ij)}$ then i belongs in the O set, $V_{(i)}$ peak is already in the T tree, j belongs in the P set , and $V_{(j)}$ peak has not been attached in the T tree yet. We put $V_{(j)}$ in the T tree, we change the O set by putting the j pointer, and we also change the P set by removing the j pointer.

The pseudo code of the algorithm is as follows.

INPUT :$n,c[e_{(ij)}],i,j$ *belonging to* $\{1,...,n\}$.

OUTPUT: p (j) *$j=2... n$ (pointer of peaks j father in the T tree).*

Steps 1. : (initializations). $O= \{1\}$ ($V_{(1)}$ root of the *T* tree). $P=\{2,...,n\}$ For every *j* belonging to P :$e(j):=c[e(j1)]$, $p(j)=1$

(All peaks connected to the root. By definition of the cost function: $e(j) =infinite$ when $V(j)$ does not connect to $V(1)$.).

2. Choose a ***k*** for which $e(k) <=e(j)$ for every *j* belonging to *P*. In case of tight choose the smaller one.

Exchange the ***O*** set with the set produced by the union of the ***O*** set and ***{k}.*** Exchange the ***P*** set with the set produced by the difference of the ***P*** set and ***{k}***. ***(P<-P-{k})*** If $P=0$ then stop.

3. For every *j* belonging to *P* compare $e(j)$ with $c[e(kj)]$.

If $e(j) >c[e(kj)]$ exchange $e(j) <-c(e(kj))$. Go back to Step 1.

APPENDIX C

Table C.1: Percentage coverage from Primary school at different buffer distance

S. No.	Mandal name	Buffer distance (m)				
		500	1000	1500	2000	2500
1	Nellikuddur	35.39	58.36	68.20	78.07	99.18
2	Bachannapet	98.62	98.62	100	100	100
3	Cheriyal	82.50	89.65	98.80	100	100
4	Devaruppala	65.62	76.64	82.74	100	100
5	Maddur	76.58	92.70	100	100	100
6	Narsampet	78.62	95.64	100	100	100
7	Parkala	18.65	23.45	28.76	39.61	47.40
8	Palakurthi	78.69	94.59	100	100	100
9	Sangem	83.67	99.71	100	100	100
10	Thorrur	82.36	92.69	100	100	100
	Average	70.07	82.21	87.85	91.77	94.66

Table C.2: Percentage coverage from for Middle school at different buffer distance

S. No.	Mandal name	Buffer distance in (m)				
		1000	2000	3000	4000	5000
1	Nellikuddur	37.73	64.81	82.01	91.04	100
2	Bachannapet	83.81	89.65	100	100	100
3	Cheriyal	74.01	86.06	95.09	100	100
4	Devaruppala	35.18	54.33	71.78	77.96	86.96
5	Maddur	15.56	33.67	37.68	54.69	64.98
6	Narsampet	71.65	88.36	96.78	100	100
7	Parkala	36.54	59.85	95.32	100	100
8	Palakurthi	34.52	41.86	61.75	73.06	79.68
9	Sangem	82.96	98.65	100	100	100
10	Thorrur	48.63	60.25	69.25	89.52	100
	Average	52.06	67.75	80.97	88.63	93.16

Table C.3: Percentage coverage from for High school at different buffer distance

S.No.	Mandal name	Buffer distance in (m)						
		1000	2000	3000	4000	5000	6000	7000
1	Nellikuddur	22.39	38.28	40.35	54.79	75.62	79.23	89.17
2	Bachannapet	61.52	75.63	86.32	96.14	100	100	100
3	Cheriyal	55.74	72.63	81.50	93.65	100	100	100
4	Devaruppala	68.75	75.25	97.83	100	100	100	100
5	Maddur	55.21	78.56	90.15	100	100	100	100
6	Narsampet	47.89	50.16	57.89	71.65	75.89	79.60	87.65

7	Parkala	51.26	63.80	88.85	100	100	100	100
8	Palakurthi	62.35	72.96	95.86	100	100	100	100
9	Sangem	43.75	79.65	81.56	94.16	100	100	100
10	Thorrur	58.69	73.25	86.48	100	100	100	100
	Average	52.76	68.02	80.68	91.04	95.15	95.88	97.68

Table C.4: Percentage coverage from for Degree College at different buffer distance

S. No.	Mandal name	Buffer distance in (m)						
		1000	2000	4000	6000	8000	10000	12000
1	Nellikuddur	8.42	10.55	24.58	38.28	64.97	68.92	81.20
2	Bachannapet	-	-	-	-	-	-	-
3	Cheriyal	23.50	25.01	42.87	51.36	75.73	82.71	94.62
4	Devaruppala	-	-	-	-	-	-	-
5	Maddur	13.85	18.99	41.45	76.47	90.65	100	100
6	Narsampet	-	-	-	-	-	-	-
7	Parkala	-	-	-	-	-	-	-
8	Palakurthi	14.06	14.06	34.87	52.86	81.06	92.64	100
9	Sangem	-	-	-	-	-	-	-
10	Thorrur	-	-	-	-	-	-	-
	Average	14.96	17.15	35.94	54.74	78.10	86.07	93.96

Table C.5: Percentage coverage from for ANM center at different buffer distance

S.No.	Mandal name	Buffer distance in (m)							
		1000	2000	3000	4000	5000	6000	8000	10000
1	Nellikuddur	0.25	4.92	10.00	31.23	35.12	40.23	73.70	94.73
2	Bachannapet	49.65	65.41	71.63	88.36	100	100	100	100
3	Cheriyal	46.52	54.89	71.56	100	100	100	100	100
4	Devaruppala	50.15	58.28	77.36	88.69	100	100	100	100
5	Maddur	54.12	72.65	85.69	100	100	100	100	100
6	Narsampet	34.56	88.45	97.65	100	100	100	100	100
7	Parkala	55.62	93.14	100	100	100	100	100	100
8	Palakurthi	57.12	65.25	91.81	100	100	100	100	100
9	Sangem	25.48	41.63	62.63	81.00	100	100	100	100
10	Thorrur	59.56	78.85	91.47	100	100	100	100	100
	Average	43.30	62.35	75.98	88.93	93.51	94.02	97.37	99.47

Table C.6: Percentage coverage from for PHC center at different buffer distance

S. No	Mandal name	Buffer distance in (m)							
		1000	2000	3000	4000	5000	6000	8000	10000
1	Nellikuddur	10.86	35.18	56.54	78.72	99.87	100	100	100
2	Bachannapet	16.24	18.35	22.61	24.56	47.85	56.84	62.05	83.50

3	Cheriyal	24.26	27.56	52.36	67.89	91.56	100	100	100
4	Devaruppala	7.30	14.31	21.58	26.81	37.89	46.15	52.80	65.13
5	Maddur	16.12	21.48	29.75	36.58	42.58	53.87	62.94	85.86
6	Narsampet	44.15	54.86	64.75	78.65	90.15	100	100	100
7	Parkala	5.10	14.25	19.86	27.85	52.14	72.45	90.45	100
8	Palakurthi	14.05	14.05	21.97	34.87	40.91	52.15	81.45	92.94
9	Sangem	10.25	13.58	17.89	28.96	50.26	65.82	93.25	100
10	Thorrur	26.35	30.25	33.45	37.58	46.69	62.25	89.96	97.85
	Averge	17.47	24.39	34.08	44.25	59.99	70.95	83.29	92.53

Table C.7: Percentage coverage from for CHC center at different buffer distance

S. No.	Mandal name	Buffer distance in (m)						
		1000	2000	4000	6000	8000	10000	12000
1	Nellikuddur	2.28	4.54	16.35	21.04	37.91	51.04	64.81
2	Bachannapet							
3	Cheriyal							
4	Devaruppala							
5	Maddur							
6	Narsampet	38.45	44.15	62.40	74.18	91.58	100	100
7	Parkala							
8	Palakurthi	14.06	14.06	34.87	52.86	81.06	92.64	100
9	Sangem							
10	Thorrur	26.35	30.25	37.58	62.25	89.96	97.85	100
	Average	20.29	23.25	37.80	52.58	75.13	85.38	91.20

Table C.8: Percentage coverage from for Veterinary Hospital at different buffer distance

S.No.	Mandal name	Buffer distance in (m)							
		1000	2000	3000	4000	5000	6000	7000	8000
1	Nellikuddur	4.07	10.16	24.94	42.12	49.15	63.96	82.05	83.89
2	Bachannapet	21.05	28.26	36.29	44.61	67.52	80.35	83.29	89.27
3	Cheriyal	37.47	49.85	56.21	72.97	78.52	88.89	100	100
4	Devaruppala	7.38	8.57	15.69	23.74	27.19	37.15	51.59	62.29
5	Maddur	14.15	24.70	44.59	61.50	73.58	87.45	100	100
6	Narsampet	48.36	61.25	75.89	86.94	100	100	100	100
7	Parkala	21.83	29.05	53.15	62.13	72.15	75.15	82.60	94.20
8	Palakurthi								
9	Sangem	10.47	13.91	17.85	28.25	50.28	65.47	88.65	93.48
10	Thorrur	34.45	40.78	49.65	54.25	78.58	87.69	95.59	100
	Average	22.14	29.61	41.58	52.95	66.33	76.23	87.09	91.46

Table C.9: Percentage coverage from for Bus Stand at different buffer distance

S. No.	Mandal name	Buffer distance in (m)					
		500	1000	1500	2000	2500	3000
1	Nellikuddur	10.75	16.87	33.69	58.48	62.35	75.89
2	Bachannapet	75.62	87.66	100	100	100	100
3	Cheriyal	69.75	81.56	87.45	93.65	100	100
4	Devaruppala	58.77	70.15	74.25	81.50	96.14	100
5	Maddur	84.56	91.93	97.25	100	100	100
6	Narsampet	72.59	82.79	89.65	95.45	100	100
7	Parkala	-	-	-	-	-	-
8	Palakurthi	67.89	78.45	85.15	90.18	95.78	100
9	Sangem	72.89	88.65	94.56	98.45	100	100
10	Thorrur	77.59	82.56	84.56	87.81	93.25	98.25
Average		65.60	75.62	82.95	89.50	94.17	97.13

Table C.10: Percentage coverage from for Post Office at different buffer distance

S. No.	Mandal name	Buffer distance in (m)						
		1000	2000	3000	4000	5000	6000	8000
1	Nellikuddur	11.01	16.67	30.35	45.12	50.76	63.58	92.57
2	Bachannapet	93.64	100	100	100	100	100	100
3	Cheriyal	31.39	37.45	43.25	68.45	72.15	74.58	91.50
4	Devaruppala	7.30	14.31	21.58	26.81	37.89	46.15	52.80
5	Maddur	87.16	100	100	100	100	100	100
6	Narsampet	90.18	100	100	100	100	100	100
7	Parkala	-	-	-	-	-	-	-
8	Palakurthi	14.06	14.06	22.59	34.87	41.89	52.86	81.06
9	Sangem	33.25	55.48	71.58	90.15	100	100	100
10	Thorrur	26.35	30.25	33.45	37.58	46.69	62.25	89.96
Average		43.82	52.02	58.09	67.00	72.15	77.71	89.77

Table C.11: Percentage coverage from for Petrol Outlet at different buffer distance

S. No.	Mandal name	Buffer distance in (m)						
		1000	2000	4000	6000	8000	10000	12000
1	Nellikuddur	8.42	10.55	24.58	38.28	64.97	68.92	81.20
2	Bachannapet	16.24	18.35	24.56	56.84	62.05	83.50	100
3	Cheriyal	18.25	20.63	37.58	53.69	75.26	82.45	98.40
4	Devaruppala	32.15	41.58	58.46	81.58	100	100	100
5	Maddur	-	-	-	-	-	-	-
6	Narsampet	35.65	44.69	62.40	75.42	96.18	100	100
7	Parkala	-	-	-	-	-	-	-
8	Palakurthi	14.06	14.06	34.87	52.86	81.06	92.64	100
9	Sangem	-	-	-	-	-	-	
10	Thorrur	26.36	30.35	37.58	62.85	89.88	97.08	100
Average		21.59	25.74	40.00	60.22	81.34	89.23	97.09

APPENDIX D Table D.1: VFI values of habitations in Nellikudur mandal

S. no.	Habitation	Educational facility index	Medical facility index	Transportation and communication facility index	Market facility index	VFI
1	Alair	0.25	0.25	0.22	0.33	1.05
2	Ammuru thanda	0.42	0.17	0.22	0.33	1.24
3	Avulega thanda	0.33	0.17	0.11	0	0.61
4	Badi tanda	0.25	0.17	0.22	0.33	0.96
5	Badi thanda	0.08	0.17	0.11	0	0.52
6	Badivath thanda	0.08	0.17	0.11	0	0.55
7	Bagna thanda	0.17	0.08	0.33	0.33	0.91
8	Bancharai tanda	0.33	0.17	0.00	0	0.69
9	Bandamide thanda	0.25	0.25	0.22	0.33	1.21
10	Banjara thanda	0.17	0.17	0.11	0.33	0.77
11	Bheemula tanda	0.17	0.08	0.11	0.33	0.91
12	Bhukya Laxman thanda	0.42	0.17	0.11	0.33	1.02
13	Bhukya thanda	0.25	0.17	0.11	0.33	0.94
14	Bodlada	0.17	0.08	0.22	0	0.47
15	Bodya thanda	0.08	0.25	0.22	0.33	0.88
16	Bokya thanda	0.25	0.17	0.22	0.33	0.96
17	Borogumatta tanda	0.08	0.08	0.11	0	0.28
18	Bramanakothapalle	0.08	0.08	0.22	0	0.39
19	Brlukunda thanda	0.42	0.17	0.22	0	0.80
20	Camp thanda	0.25	0.25	0.22	0.33	1.05
21	Chakya thanda	0.17	0.17	0.11	0.33	0.85
22	Chathru thanda	0.42	0.17	0.11	0.33	1.21
23	Cherlaxmi thanda	0.42	0.50	0.44	0.33	1.80
24	Chervu vumahand thanda	0.25	0.25	0.11	0	0.77
25	Chinnamupparam	0.75	0.25	0.22	0.33	1.55

26	Chinnangaram	0.42	0.17	0.11	0.33	1.10
27	Darsu thanda	0.33	0.25	0.22	0.33	0.88
28	Dharavat thanda	0.08	0.17	0.11	0	0.36
29	Dharvath thanda	0.33	0.17	0.11	0.33	1.21
30	Gandichandru tanda	0.25	0.17	0.22	0.33	1.07
31	Gillya thanda	0.17	0.17	0.11	0.33	0.66
32	Gopalapuram	0.25	0.50	0.00	0.33	1.16
33	Govind tanda	0.25	0.17	0.22	0.33	0.99
34	Govula Guta thanda	0.17	0.17	0.22	0	0.63
35	Gugoloath Laxman thanda	0.33	0.17	0.00	0.33	1.10
36	Gugoloth molath thanda	0.17	0.17	0.11	0.33	0.85
37	Hanuma thanda	0.42	0.17	0.11	0.33	1.21
38	Hemla thanda	0.25	0.25	0.11	0	0.61
39	Jagadaamba thanda	0.42	0.17	0.22	0.33	1.24
40	Jairam thanda	0.17	0.08	0.11	0.33	0.77
41	Jama thanda	0.25	0.17	0.22	0.33	0.99
42	Jamala thanda	0.50	0.33	0.11	0.33	1.27
43	Jamla thanda	0.08	0.17	0.33	0.33	0.99
44	Jarvbanda thanda	0.33	0.25	0.22	0.33	0.88
45	Jhatoah thanda	0.08	0.17	0.11	0	0.63
46	Kachikal	0.33	0.17	0.11	0	0.72
47	Kasna thanda	0.25	0.17	0.11	0.33	0.85
48	Keemanaik thanda	0.42	0.17	0.11	0.33	1.21
49	Keshya thanda	0.17	0.17	0.11	0.33	0.85
50	Kondengulagutta thanda	0.75	0.25	0.33	0	1.33
51	Kotha thanda	0.25	0.08	0.00	0.33	0.86
52	Kothur tanda	0.08	0.17	0.00	0	0.25
53	Kottapalli tanda	0.08	0.08	0.22	0	0.39
54	Kummarakunta thanda	0.42	0.25	0.11	0	0.77

55	Kunaikunta thanda	0.42	0.17	0.22	0.33	1.13
56	Lalu tanda	0.17	0.08	0.11	0.33	0.69
57	Lalu thanda	0.33	0.17	0.11	0.33	1.02
58	Lasya thanda	0.08	0.08	0.22	0.33	0.91
59	Laximipuram	0.25	0.25	0.33	0.33	1.44
60	Lokya thanda	0.42	0.25	0.44	0.33	1.44
61	Madanthurthy	0.33	0.08	0.22	0.33	1.08
62	Madya thanda	0.25	0.25	0.11	0	0.61
63	Mangali thanda	0.25	0.25	0.11	0.33	1.21
64	Mangya thanda	0.25	0.25	0.11	0.33	1.08
65	Mangya thanda	0.17	0.17	0.22	0	0.50
66	Matru thanda	0.33	0.25	0.22	0.33	0.80
67	Matya thanda	0.17	0.17	0.00	0.33	0.77
68	Mecharajpalle	0.33	0.25	0.33	0	0.92
69	Motiya thanda	0.25	0.17	0.22	0.33	1.07
70	Mudugutta tanda	0.25	0.17	0.22	0	0.63
71	Mukunda thanda	0.25	0.25	0.11	0.33	1.13
72	Munugalvedu	0.33	0.08	0.11	0.33	0.94
73	Nainala	0.33	0.17	0.22	0.33	1.05
74	Nalllagutta thanda	0.25	0.17	0.22	0.33	1.07
75	Nam thanda	0.17	0.08	0.11	0.33	0.69
76	Nandya thanda	0.25	0.17	0.00	0.33	0.94
77	Narasimlagudem	0.08	0.17	0.00	0.33	0.85
78	Narayanpuram	0.33	0.25	0.22	0.33	1.21
79	Nellikudur	0.33	0.17	0.67	0.33	1.49
80	Nimma thanda	0.42	0.17	0.22	0.33	1.24
81	Ontigudisa thanda	0.42	0.25	0.11	0	0.77
82	Padamatiggadda thanda	0.08	0.08	0.00	0	0.25
83	Panthulu thanda	0.33	0.25	0.11	0.33	1.21

84	Panthulu thanda	0.42	0.08	0.11	0.33	0.86
85	Panthulya thanda	0.17	0.08	0.11	0.33	0.77
86	Paravathammagudem	0.42	0.17	0.22	0.33	1.13
87	Pedda thanda	0.17	0.17	0.11	0.33	1.32
88	Pedda thanda	0.42	0.08	0.11	0	0.52
89	Pekla thanda	0.42	0.25	0.22	0.33	1.21
90	Pinya thanda	0.17	0.08	0.55	0.33	1.13
91	Rajulakothapalle	0.67	0.33	0.22	0.33	1.66
92	Rajya thanda	0.25	0.25	0.11	0	0.61
93	Rama chandru thanda	0.17	0.25	0.11	0.33	1.13
94	Ramachilukala Boda thanda	0.08	0.17	0.00	0	0.52
95	Ramannagudem	0.33	0.17	0.22	0	0.72
96	Ramanniapuram	0.25	0.17	0.44	0	0.97
97	Ramoji tanda	0.33	0.17	0.33	0.33	1.27
98	Ramsingh thanda	0.33	0.25	0.44	0.33	1.44
99	Rathi Ram thanda	0.42	0.17	0.22	0.33	1.13
100	Rathya thanda	0.33	0.25	0.22	0.33	1.21
101	Ravirala	0.42	0.17	0.22	0.33	1.32
102	Regadi thanda	0.42	0.33	0.33	0.33	1.52
103	Rekula thanda	0.42	0.50	0.44	0.33	1.80
104	Samya thanda	0.25	0.25	0.11	0	0.61
105	Sandhya thanda	0.25	0.25	0.00	0.33	0.94
106	Sapvat thanda	0.33	0.75	0.67	0.33	2.08
107	Sapvath thanda	0.25	0.17	0.11	0.33	0.96
108	Sathya thanda	0.17	0.17	0.22	0.33	0.88
109	Singaladevi tanda	0.17	0.17	0.11	0	0.44
110	Singya thanda	0.25	0.17	0.33	0.33	1.07
111	Sitarampuram	0.42	0.33	0.22	0.33	1.38
112	Society thanda	0.42	0.17	0.44	0.33	1.02

113	Somula thanda	0.33	0.25	0.11	0.33	1.24
114	Sovula thanda	0.25	0.17	0.22	0	0.55
115	Sriramgirii	0.25	0.17	0.22	0.33	0.96
116	Sundar thanda	0.33	0.25	0.22	0.33	1.21
117	Sundera thanda	0.25	0.17	0.00	0	0.53
118	Sunnapurolle thanda	0.00	0.17	0.00	0.33	0.85
119	Surya thanda	0.33	0.25	0.00	0.33	1.21
120	Tara singh thanda	0.25	0.17	0.11	0.33	1.05
121	Tekya thanda	0.17	0.08	0.44	0.33	1.13
122	Thejya thanda	0.33	0.08	0.11	0	0.64
123	Thimmna thanda	0.17	0.17	0.22	0.33	0.99
124	Thotya thanda	0.42	0.17	0.22	0	0.91
125	Tulsaya thanda	0.08	0.25	0.22	0.33	0.88
126	Tulsya thanda	0.25	0.25	0.11	0.33	1.30
127	Umla thanda	0.33	0.33	0.22	0.33	1.30
128	Vachiya thanda	0.33	0.25	0.22	0.33	1.21
129	Varambanda thanda	0.33	0.17	0.44	0	1.02
130	Vasuram thanda	0.08	0.17	0.22	0.33	0.99
131	Vavilala	0.33	0.25	0.11	0	0.77
132	Vekati thanda	0.42	0.25	0.22	0.33	1.21
133	Venkatapuram	0.58	0.33	0.44	1	2.44
134	Visra thanda	0.08	0.25	0.44	0.33	1.10
135	Voskechandru tanda	0.17	0.17	0.22	0.33	0.88
136	Yerrabelligudem	0.42	0.17	0.11	0	0.80

APPENDIX E Table E.1: Turn Feature Class Attribute Prepared on MX Excel

NODE#	ARC1#	ARC2#	ANGLES	TURNS	MINUTES
4	109	112	0	Straight	0.30
4	109	111	90	Left	0.35
4	112	109	0	Straight	0.30
4	112	111	-90	Right	0.25
4	111	109	-90	Right	0.25
4	111	112	90	Left	0.35
8	104	105	-90	Right	0.25
8	104	109	0	Straight	0.30
8	109	104	0	Straight	0.30
8	109	105	90	Left	0.35
8	105	104	90	Left	0.35
8	105	109	-90	Right	0.25
12	101	106	-90	Right	0.25
12	101	107	0	Straight	0.30
12	106	101	90	Left	0.35
12	106	107	-90	Right	0.25
12	107	101	0	Straight	0.30
12	107	106	90	Left	0.35
14	97	98	-90	Right	0.25
14	97	108	0	Straight	0.30
14	98	97	90	Left	0.35
14	98	108	-90	Right	0.25
14	108	97	0	Straight	0.30
14	108	98	90	Left	0.35
15	96	101	0	Straight	0.30
15	96	103	90	Left	0.35
15	101	96	0	Straight	0.30
15	101	103	-90	Right	0.25
15	103	96	-90	Right	0.25
15	103	101	90	Left	0.35
16	95	98	90	Left	0.35
16	95	110	-90	Right	0.25
16	98	95	-90	Right	0.25
16	98	110	90	Left	0.35
16	110	95	90	Left	0.35
16	110	98	-90	Right	0.25

17	94	96	0	Straight	0.30
17	94	99	-90	Right	0.25
17	96	94	0	Straight	0.30
17	96	99	90	Left	0.35
17	99	94	90	Left	0.35
17	99	96	-90	Right	0.25
18	93	104	0	Straight	0.30
18	93	100	90	Left	0.35
18	100	93	-90	Right	0.25
18	104	93	0	Straight	0.30
18	100	104	90	Left	0.35
18	104	100	-90	Right	0.25
19	92	99	90	Left	0.35
19	92	102	-90	Right	0.25
19	99	92	-90	Right	0.25
19	99	102	90	Left	0.35
19	102	92	90	Left	0.35
19	102	99	-90	Right	0.25
20	78	90	-90	Right	0.25
20	78	91	0	Straight	0.30
20	90	78	90	Left	0.35
20	90	91	-90	Right	0.25
20	91	78	0	Straight	0.30
20	91	90	90	Left	0.35
21	89	88	90	Left	0.35
21	89	95	0	Straight	0.30
21	88	89	-90	Right	0.25
21	88	95	90	Left	0.35
21	95	88	-90	Right	0.25
21	95	89	0	Straight	0.30
22	86	87	-90	Right	0.25
22	86	92	90	Left	0.35
22	87	86	90	Left	0.35
22	87	92	-90	Right	0.25
22	92	86	-90	Right	0.25
22	92	87	90	Left	0.35
23	84	85	-90	Right	0.35
23	84	90	0	Straight	0.30
23	85	84	90	Left	0.35

23	85	90	-90	Right	0.25
23	90	84	0	Straight	0.30
23	90	85	90	Left	0.35
25	82	93	0	Straight	0.30
25	82	83	-90	Right	0.25
25	93	82	0	Straight	0.30
25	93	83	90	Left	0.35
25	83	93	-90	Right	0.25
25	83	82	90	Left	0.35
26	80	81	-90	Right	0.25
26	80	88	0	Straight	0.30
26	80	97	-90	Left	0.35
26	81	80	90	Left	0.35
26	81	88	-90	Right	0.25
26	81	97	0	Straight	0.30
26	88	80	0	Straight	0.30
26	88	81	90	Left	0.35
26	88	97	-90	Right	0.25
26	97	80	-90	Right	0.25
26	97	81	0	Straight	0.30
26	97	88	90	Left	0.35
29	76	77	-90	Right	0.25
29	76	80	0	Straight	0.30
29	77	76	90	Left	0.35
29	77	80	-90	Right	0.25
29	80	76	0	Straight	0.30
29	80	77	90	Left	0.35
30	74	75	-90	Right	0.25
30	74	76	0	Straight	0.30
30	74	87	90	Left	0.35
30	75	74	90	Left	0.35
30	75	76	-90	Right	0.25
30	75	87	0	Straight	0.30
30	76	74	0	Straight	0.30
30	76	75	90	Left	0.35
30	76	87	-90	Right	0.25
30	87	74	-90	Right	0.25
30	87	75	0	Straight	0.30
30	87	76	90	Left	0.35

31	72	73	-90	Right	0.25
31	72	91	90	Left	0.35
31	73	72	90	Left	0.35
31	73	91	0	Straight	0.30
31	91	72	-90	Right	0.25
31	91	73	0	Straight	0.30
33	70	73	0	Straight	0.30
33	70	94	-90	Right	0.25
33	73	70	0	Straight	0.30
33	73	94	90	Left	0.35
33	94	70	90	Left	0.35
33	94	73	-90	Right	0.25
34	68	69	-90	Right	0.25
34	68	77	90	Left	0.35
34	68	81	0	Straight	0.30
34	69	68	90	Left	0.35
34	69	77	0	Straight	0.30
34	69	81	-90	Right	0.25
34	77	68	-90	Right	0.25
34	77	69	0	Straight	0.30
34	77	81	90	Left	0.35
34	81	68	0	Straight	0.30
34	81	69	90	Left	0.35
34	81	77	-90	Right	0.25
36	66	78	-90	Right	0.25
36	66	85	90	Left	0.35
36	85	78	90	Left	0.35
36	85	66	-90	Right	0.25
36	78	66	90	Left	0.35
36	78	85	-90	Right	0.25
37	65	82	0	Straight	0.30
37	65	67	-90	Right	0.25
37	67	65	90	Left	0.35
37	67	82	-90	Right	0.25
37	82	65	0	Straight	0.30
37	82	67	90	Left	0.35
38	64	74	-90	Right	0.25
38	64	86	0	Straight	0.30
38	74	64	90	Left	0.35

38	74	86	-90	Right	0.25
38	86	64	0	Straight	0.30
38	86	74	90	Left	0.35
39	62	63	0	Straight	0.30
39	62	66	-90	Right	0.25
39	63	62	0	Straight	0.30
39	63	66	90	Left	0.35
39	66	62	90	Left	0.35
39	66	63	-90	Right	0.25
40	60	61	-90	Right	0.25
40	60	64	90	Left	0.35
40	61	60	90	Left	0.35
40	61	64	-90	Right	0.25
40	64	60	-90	Right	0.25
40	64	61	90	Left	0.35
41	59	60	-90	Right	0.25
41	59	70	0	Straight	0.30
41	60	59	90	Left	0.35
41	60	70	-90	Right	0.25
41	70	59	0	Straight	0.30
41	70	60	90	Left	0.35
42	58	68	0	Straight	0.30
42	58	75	90	Left	0.35
42	68	58	0	Straight	0.30
42	68	75	-90	Right	0.25
42	75	58	-90	Right	0.25
42	75	68	90	Left	0.35
43	56	57	90	Left	0.35
43	56	59	0	Straight	0.30
43	57	56	-90	Right	0.25
43	57	59	90	Left	0.35
43	59	56	0	Straight	0.30
43	59	57	-90	Right	0.25
44	53	54	-90	Right	0.25
44	53	55	0	Straight	0.30
44	53	71	90	Left	0.35
44	54	55	-90	Right	0.25
44	54	71	0	Straight	0.30
44	54	53	90	Left	0.35

44	55	53	0	Straight	0.30
44	55	54	90	Left	0.35
44	55	71	-90	Right	0.25
44	71	53	-90	Right	0.25
44	71	54	0	Straight	0.30
44	71	55	90	Left	0.35
45	52	89	-90	Right	0.25
45	52	69	90	Left	0.35
45	69	52	-90	Right	0.25
45	69	89	90	Left	0.35
45	89	52	90	Left	0.35
45	89	69	-90	Right	0.25
46	51	65	0	Straight	0.30
46	51	50	90	Left	0.35
46	50	51	-90	Right	0.25
46	50	65	90	Left	0.35
46	65	50	-90	Right	0.25
46	65	51	0	Straight	0.30
47	48	49	-90	Right	0.25
47	48	56	90	Left	0.35
47	49	48	90	Left	0.35
47	49	56	0	Straight	0.30
47	56	48	-90	Right	0.25
47	56	49	0	Straight	0.30
48	47	52	90	Left	0.35
48	47	53	-90	Right	0.25
48	52	47	-90	Right	0.25
48	52	53	90	Left	0.35
48	53	47	90	Left	0.35
48	53	52	-90	Right	0.25
49	45	46	-90	Right	0.25
49	45	58	0	Straight	0.30
49	46	45	90	Left	0.35
49	46	58	-90	Right	0.25
49	58	45	0	Straight	0.30
49	58	46	90	Left	0.35
50	44	50	-90	Right	0.25
50	44	55	90	Left	0.35
50	50	44	90	Left	0.35

50	50	55	0	Straight	0.30
50	55	44	-90	Right	0.25
50	55	50	0	Straight	0.30
51	42	43	-90	Right	0.25
51	42	62	0	Straight	0.30
51	43	42	90	Left	0.35
51	43	62	-90	Right	0.25
51	62	42	0	Straight	0.30
51	62	43	90	Left	0.35
52	41	57	-90	Right	0.25
52	41	72	90	Left	0.35
52	57	41	90	Left	0.35
52	57	72	-90	Right	0.25
52	72	41	-90	Right	0.25
52	72	57	90	Left	0.35
53	40	41	-90	Right	0.25
53	40	43	90	Left	0.35
53	41	40	90	Left	0.35
53	41	43	-90	Right	0.25
53	43	40	-90	Right	0.25
53	43	41	90	Left	0.35
54	38	39	-90	Right	0.25
54	38	42	90	Left	0.35
54	39	38	90	Left	0.35
54	39	42	0	Straight	0.30
54	42	38	-90	Right	0.25
54	42	39	0	Straight	0.30
55	37	46	90	Left	0.35
55	37	47	0	Straight	0.30
55	46	37	-90	Right	0.25
55	46	47	90	Left	0.35
55	47	37	0	Straight	0.30
55	47	46	-90	Right	0.25
56	36	45	0	Straight	0.30
56	36	61	90	Left	0.35
56	45	36	0	Straight	0.30
56	45	61	-90	Right	0.25
56	61	36	-90	Right	0.25
56	61	45	90	Left	0.35

57	35	38	-90	Right	0.25
57	35	63	90	Left	0.35
57	38	35	90	Left	0.35
57	38	63	-90	Right	0.25
57	63	35	-90	Right	0.25
57	63	38	90	Left	0.35
58	33	51	0	Straight	0.30
58	33	34	90	Left	0.35
58	34	51	90	Left	0.35
58	34	33	-90	Right	0.25
58	51	33	0	Straight	0.30
58	51	34	-90	Right	0.25
59	32	44	-90	Right	0.25
59	32	54	90	Left	0.35
59	44	32	90	Left	0.35
59	44	54	-90	Right	0.25
59	54	32	-90	Right	0.25
59	54	44	90	Left	0.35
60	30	31	90	Left	0.35
60	30	35	-90	Right	0.25
60	31	30	-90	Right	0.25
60	31	35	90	Left	0.35
60	35	30	90	Left	0.35
60	35	31	-90	Right	0.25
61	29	36	-90	Right	0.25
61	29	49	0	Straight	0.30
61	36	29	90	Left	0.35
61	36	49	-90	Right	0.25
61	49	29	0	Straight	0.30
61	49	36	90	Left	0.35
62	27	28	90	Left	0.35
62	27	48	-90	Right	0.25
62	28	27	-90	Right	0.25
62	28	48	90	Left	0.35
62	48	27	90	Left	0.35
62	48	28	-90	Right	0.25
63	39	26	-90	Right	0.25
63	39	26	90	Left	0.35
63	26	39	90	Left	0.35

63	26	40	0	Straight	0.30
63	40	39	-90	Right	0.25
63	40	26	0	Straight	0.30
65	24	25	-90	Right	0.25
65	24	30	90	Left	0.35
65	25	24	90	Left	0.35
65	25	30	0	Straight	0.30
65	30	24	-90	Right	0.25
65	30	25	0	Straight	0.30
66	23	33	0	Straight	0.30
66	23	79	-90	Right	0.25
66	33	23	0	Straight	0.30
66	33	79	90	Left	0.35
66	79	23	90	Left	0.35
66	79	33	-90	Right	0.25
67	21	22	-90	Right	0.25
67	21	29	90	Left	0.35
67	22	21	90	Left	0.35
67	22	29	0	Straight	0.30
67	29	21	-90	Right	0.25
67	29	22	0	Straight	0.30
68	20	23	0	Straight	0.30
68	20	34	90	Left	0.35
68	34	20	-90	Right	0.25
68	34	23	90	Left	0.35
68	23	34	-90	Right	0.25
68	23	20	0	Straight	0.30
69	19	26	90	Left	0.35
69	19	28	-90	Right	0.25
69	26	19	-90	Right	0.25
69	26	28	0	Straight	0.30
69	28	19	90	Left	0.35
69	28	26	0	Straight	0.30
70	17	18	-90	Right	0.25
70	17	21	0	Straight	0.30
70	17	27	90	Left	0.35
70	18	17	90	Left	0.35
70	18	21	-90	Right	0.25
70	18	27	0	Straight	0.30

70	21	17	0	Straight	0.30
70	21	18	90	Left	0.35
70	21	27	-90	Right	0.25
70	27	17	-90	Right	0.25
70	27	18	0	Straight	0.30
70	27	21	90	Left	0.35
73	16	19	-90	Right	0.25
73	16	25	90	Left	0.35
73	19	16	90	Left	0.35
73	19	25	0	Straight	0.30
73	25	16	-90	Right	0.25
73	25	19	0	Straight	0.30
75	15	18	90	Left	0.35
75	15	22	0	Straight	0.30
75	18	15	-90	Right	0.25
75	18	22	90	Left	0.35
75	22	15	0	Straight	0.30
75	22	18	-90	Right	0.25
78	13	14	-90	Right	0.25
78	13	16	90	Left	0.35
78	14	13	90	Left	0.35
78	14	16	-90	Right	0.25
78	16	13	-90	Right	0.25
78	16	14	90	Left	0.35
79	11	12	-90	Right	0.25
79	11	14	90	Left	0.35
79	11	17	0	Straight	0.30
79	12	11	90	Left	0.35
79	12	14	0	Straight	0.30
79	12	17	-90	Right	0.25
79	14	11	-90	Right	0.25
79	14	12	0	Straight	0.30
79	14	17	90	Left	0.35
79	17	11	0	Straight	0.30
79	17	12	90	Left	0.35
79	17	14	-90	Right	0.25
80	9	10	-90	Right	0.25
80	9	13	0	Straight	0.30
80	10	9	90	Left	0.35

80	10	13	-90	Right	0.25
80	13	9	0	Straight	0.30
80	13	10	90	Left	0.35
83	7	8	-90	Right	0.25
83	7	11	0	Straight	0.30
83	8	7	90	Left	0.35
83	8	11	-90	Right	0.25
83	11	7	0	Straight	0.30
83	11	8	90	Left	0.35
85	5	6	0	Straight	0.30
85	5	10	-90	Right	0.25
85	6	5	0	Straight	0.30
85	6	10	90	Left	0.35
85	10	5	90	Left	0.35
85	10	6	-90	Right	0.25
86	3	4	-90	Right	0.25
86	3	5	90	Left	0.35
86	4	3	90	Left	0.35
86	4	5	0	Straight	0.30
86	5	3	-90	Right	0.25
86	5	4	0	Straight	0.30
87	1	4	0	Straight	0.30
87	1	7	-90	Right	0.25
87	4	1	0	Straight	0.30
87	4	7	90	Left	0.35
87	7	1	90	Left	0.35
87	7	4	-90	Right	0.25
89	1	2	0	Straight	0.25
89	1	8	90	Left	0.35
89	2	1	0	Straight	0.30
89	2	8	-90	Right	0.25
89	8	1	-90	Right	0.25
89	8	2	90	Left	0.35

APPENDIX F

Algorithm: Prim-MST (adjMatrix)

Input: Adjacency matrix: adjMatrix[i][j] = weight of edge(i,j) (if nonzero)

```
        // inMST[i] = true once vertex i is in the MST.
1.   Initialize inMST[i] = false for all i;
2.   Initialize priority[i] = infinity for all i;
3.   priority[0] = 0
4.   numVerticesAdded = 0
     //Process vertices one by one. Note: priorities change as we proceed.
5.   while numVerticesAdded < numVertices
     // Extract best vertex.
6.   v = vertex with lowest priority that is not in MST;
     // Place in MST.
7.   inMST[v] = true
8.   numVerticesAdded = numVerticesAdded + 1
     // explore edges going out from v.
9.   for i=0 to numVertices-1
     // If there's an edge and it's not a self-loop.
10.     if i!=v and adjMatrix[v][i]>0
11.         if priority[i] > adjMatrix[v][i]
                    //New priority.
12.             priority[i] = adjMatrix[v][i]
13.             predecessor[i] = v
14.         endif
15.     endif
16.   endfor
17.  endwhile
18.  treeMatrix = adjacency matrix representation of tree using predecessor array;
19.  return treeMatrix
```

Output: Adjacent matrix representation of MS

APPENDIX G

Dijkstra's Algorithm

```
function Dijkstra(Graph, source):

    create vertex set Q

    for each vertex v in Graph:
        dist[v] ← INFINITY
        prev[v] ← UNDEFINED
        add v to Q
     dist[source] ← 0

     while Q is not empty:
         u ← vertex in Q with min dist[u]

         remove u from Q

         for each neighbor v of u:           // only v that are still in Q
             alt ← dist[u] + length(u, v)
             if alt < dist[v]:
                 dist[v] ← alt
                 prev[v] ← u

     return dist[ ], prev[ ]
```

Table H.1: Shortest distance matrix of Nellikudur mandal in normal condition

O/D	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46
1	0.0	4.5	5.1	4.5	6.9	5.1	12.5	9.3	11.0	6.4	16.2	3.7	5.6	4.5	7.2	14.6	6.1	12.7	11.5	6.2	4.6	13.4	2.5	6.7	6.7	2.6	6.6	6.1	5.6	16.6	14.8	6.0	6.5	10.4	4.8	7.6	7.7	6.3	11.7	14.9	8.5	6.0	12.9	11.1	15.0	3.1
2	4.5	0.0	9.2	4.9	10.1	9.4	5.9	6.7	14.3	12.8	26.1	0.7	10.1	4.9	7.8	15.8	11.3	13.5	19.4	5.0	9.7	16.8	5.3	14.5	11.6	5.7	11.7	4.7	8.9	14.4	15.8	12.9	9.8	11.6	2.5	12.1	6.7	9.8	17.1	15.3	13.0	9.8	16.2	18.8	22.9	6.4
3	5.1	9.2	0.0	8.9	4.0	0.3	13.1	9.2	10.4	3.7	17.9	9.2	5.2	5.6	7.5	15.4	1.0	14.5	11.2	7.4	1.4	13.0	2.6	6.1	6.5	3.3	1.3	7.1	4.9	20.8	18.7	3.0	5.0	11.3	5.9	6.2	6.5	3.5	11.1	17.3	8.0	0.9	12.5	10.6	14.5	2.1
4	4.5	4.9	8.9	0.0	12.8	9.1	5.3	5.9	7.2	12.5	12.5	8.5	8.7	4.3	2.6	9.1	9.4	6.9	11.3	4.3	7.5	9.2	9.6	5.1	6.5	5.5	10.3	4.0	7.8	13.1	9.4	11.8	7.7	5.1	9.1	8.8	2.0	12.6	13.1	10.1	9.7	9.2	9.2	8.8	12.7	10.9
5	6.9	10.1	4.0	12.8	0.0	3.9	16.9	15.7	14.1	1.5	19.8	9.4	9.2	11.4	12.4	18.4	5.0	18.3	15.1	14.0	5.3	16.6	4.3	9.9	10.2	7.4	5.0	13.7	8.7	24.2	25.0	4.8	9.6	16.4	7.7	11.0	10.6	2.3	14.9	21.2	11.8	4.8	20.3	14.4	18.3	3.7
6	5.1	9.4	0.7	9.1	3.9	0.0	12.9	9.2	10.7	3.7	18.2	9.2	5.7	9.2	8.9	15.2	0.7	14.6	11.1	14.4	1.7	13.5	2.7	8.3	6.9	3.8	1.1	11.1	5.3	17.9	18.6	2.5	6.5	12.7	6.0	7.7	10.0	3.5	10.7	17.7	8.5	1.2	12.6	10.8	14.8	2.2
7	12.5	5.9	13.1	5.3	16.9	12.9	0.0	8.5	8.3	15.3	16.4	10.8	11.5	7.1	3.9	10.6	11.9	8.3	10.4	6.9	10.1	10.5	14.1	6.2	7.6	8.3	12.8	6.6	11.1	9.6	10.4	14.0	8.7	6.3	11.6	9.8	4.8	15.1	13.9	10.8	14.1	12.0	16.9	10.1	13.7	13.5
8	9.3	6.7	9.2	5.9	15.7	9.2	8.5	0.0	10.6	16.8	17.8	8.5	10.1	4.3	4.6	12.7	9.9	10.4	11.4	2.0	7.5	12.7	11.5	7.1	9.7	5.4	9.9	2.1	8.3	11.8	12.7	11.9	9.4	8.5	7.3	10.6	3.6	7.0	14.7	12.8	11.4	9.2	12.7	10.6	14.5	11.0
9	2.2	14.3	10.4	7.2	14.1	10.7	8.3	10.6	0.0	14.0	5.6	13.5	7.2	10.2	5.8	4.4	11.3	5.0	4.5	8.6	8.9	2.6	13.0	4.2	5.5	8.3	11.5	8.6	6.6	7.6	8.4	13.1	7.8	2.1	13.8	9.0	6.9	13.7	12.8	10.0	8.5	10.6	2.3	4.0	4.8	12.4
10	6.4	12.8	3.7	12.5	1.5	3.7	15.3	16.8	14.0	0.0	19.3	9.2	8.8	9.1	12.3	18.0	4.3	18.5	14.6	11.1	5.0	16.2	4.2	9.6	9.7	7.0	4.6	11.0	8.5	23.7	24.2	4.3	10.8	15.1	7.3	11.9	10.3	2.0	15.8	20.8	12.7	3.5	20.2	13.8	18.0	3.4
11	16.2	26.1	17.9	12.5	19.8	18.2	16.4	17.8	5.6	19.3	0.0	18.1	14.3	15.6	11.3	8.7	17.5	9.3	6.6	14.3	16.0	7.0	18.8	15.9	14.4	15.4	18.6	13.9	14.3	15.6	16.2	19.9	13.3	10.8	19.0	12.2	12.3	21.0	11.4	12.5	11.3	17.4	3.4	7.0	3.0	19.5
12	3.7	1.0	9.2	8.5	9.4	9.2	10.8	8.5	13.5	9.2	18.1	0.0	9.1	4.1	6.9	14.8	9.5	12.5	14.4	4.7	7.2	14.7	5.1	10.0	10.2	5.2	10.0	4.3	8.1	13.9	14.6	11.2	9.0	10.6	1.8	10.1	5.7	10.3	13.2	14.8	11.0	8.9	15.2	14.6	18.6	5.6
13	5.6	10.1	5.2	8.7	9.2	5.7	11.5	10.1	7.2	8.8	14.3	9.1	0.0	5.2	5.6	13.7	6.2	11.5	8.1	8.6	3.8	13.7	8.0	3.0	3.3	3.3	6.6	8.3	1.8	14.7	16.0	7.9	4.3	9.5	10.0	5.5	6.5	8.8	9.6	13.9	6.4	5.4	9.6	7.5	11.4	7.4
14	4.5	4.9	5.6	4.3	11.4	9.2	7.1	4.3	10.2	9.1	15.6	4.1	5.2	0.0	3.2	11.1	6.2	8.8	11.0	2.4	4.0	11.0	8.4	6.0	6.3	2.0	6.6	2.3	4.8	10.3	11.0	7.9	7.2	6.9	4.9	8.4	2.1	9.1	12.5	11.4	9.3	5.7	16.7	10.5	14.2	7.8
15	7.2	7.8	7.5	2.5	12.4	8.9	3.9	4.6	5.8	12.3	11.3	6.9	5.6	3.2	0.0	8.1	8.8	5.8	6.6	3.0	7.2	8.0	11.2	2.6	3.8	6.5	9.4	2.7	5.2	7.2	7.8	10.9	4.9	3.8	8.0	6.1	1.1	12.1	10.4	8.3	7.1	8.6	12.1	6.0	9.8	10.7
16	14.6	15.8	15.4	9.1	18.4	15.2	10.6	12.7	4.4	18.0	8.7	14.8	13.7	11.1	8.1	0.0	14.9	2.5	11.7	11.4	13.2	2.0	17.8	8.5	9.9	12.6	15.6	11.0	11.1	7.9	8.8	17.1	12.3	4.5	16.1	13.4	9.2	18.9	17.6	5.0	14.3	14.9	5.9	12.4	8.4	17.4
17	6.1	11.3	1.0	9.4	5.0	0.7	11.9	9.9	11.3	4.3	17.5	9.5	6.2	6.2	8.8	14.9	0.0	14.7	12.3	8.2	2.4	17.0	3.3	7.2	7.5	4.6	0.4	8.0	5.9	16.8	17.5	1.6	7.0	12.7	6.8	8.2	8.0	4.2	12.2	17.8	9.1	1.8	17.0	13.7	15.7	2.7
18	12.7	13.5	14.5	6.9	18.3	14.6	8.3	10.4	5.0	18.5	9.3	12.5	11.5	8.8	5.8	2.5	14.7	0.0	9.0	8.6	12.1	2.4	14.8	8.0	9.3	10.0	14.8	8.4	8.3	6.0	6.8	16.0	10.4	2.0	13.5	11.6	6.7	18.7	13.5	2.9	12.4	13.8	6.5	8.3	8.9	15.4
19	11.5	19.4	11.2	11.3	15.1	11.1	10.4	11.4	4.5	14.6	6.6	14.4	8.1	11.0	6.6	11.7	12.3	9.0	0.0	10.0	11.4	7.3	13.9	5.1	8.0	11.0	14.2	9.7	8.1	12.2	12.9	15.5	7.0	7.0	14.7	5.8	7.8	14.9	5.3	13.2	5.0	13.3	4.4	0.8	3.5	13.2
20	6.2	5.0	7.4	4.3	14.0	14.4	6.9	2.0	8.6	11.1	14.3	4.7	8.6	2.4	3.0	11.4	8.2	8.6	10.0	0.0	5.9	11.1	9.8	5.5	6.8	3.8	8.7	0.4	8.5	12.1	12.9	10.1	8.0	6.9	5.3	9.1	2.0	10.7	13.1	11.1	10.0	7.7	15.1	8.8	12.6	9.3
21	4.6	9.7	1.4	7.5	5.3	1.7	10.1	7.5	8.9	5.0	16.0	7.2	3.8	4.0	7.2	13.2	2.4	12.1	11.4	5.9	0.0	11.5	4.0	4.8	5.1	2.2	3.0	5.8	3.5	15.4	16.1	4.3	4.7	10.2	7.4	5.9	5.5	5.0	9.9	16.6	6.7	1.8	11.4	9.1	13.0	3.5
22	13.4	16.8	13.0	9.2	16.6	13.5	10.5	12.7	2.6	16.2	7.0	14.7	13.7	11.0	8.0	1.8	17.0	2.4	7.3	11.1	11.5	0.0	15.6	6.7	8.0	10.9	14.3	10.7	9.3	7.5	8.2	15.6	10.4	4.2	15.8	11.6	9.0	16.3	15.8	4.6	12.4	13.4	4.2	6.8	6.5	15.1
23	2.5	5.3	2.6	9.6	4.3	2.7	14.1	11.5	13.0	4.0	18.8	5.1	8.0	8.4	11.2	17.8	3.3	14.8	13.9	9.8	4.0	15.6	0.0	8.7	9.1	4.7	3.7	9.6	7.5	19.2	19.9	3.5	8.7	15.3	3.4	9.8	8.0	4.0	13.9	20.2	10.7	3.6	15.7	13.3	17.3	0.6
24	6.7	14.5	6.1	5.1	9.9	8.3	6.2	7.1	4.2	9.6	15.9	10.0	3.0	6.0	2.6	8.5	7.2	8.0	5.1	5.5	4.8	6.7	8.7	0.0	1.5	4.0	7.7	5.5	2.7	11.6	12.4	8.7	2.5	6.4	10.6	3.8	3.9	9.6	7.9	10.8	4.6	6.4	6.5	4.6	8.6	8.1
25	6.7	11.6	6.5	6.5	10.2	6.9	7.6	9.7	5.5	9.7	14.4	10.2	3.3	6.3	3.8	9.9	7.5	9.3	8.0	6.8	5.1	8.0	9.1	1.5	0.0	4.3	7.7	6.8	1.5	15.9	16.7	9.0	1.1	8.0	12.5	2.3	5.2	9.9	6.4	13.1	3.1	6.7	8.2	6.0	10.0	8.6

O/D	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46
26	2.6	5.7	3.3	5.5	7.4	3.8	8.3	5.4	8.3	7.0	15.4	5.2	3.3	2.0	6.5	12.6	4.6	10.0	11.0	3.8	2.2	10.9	4.7	4.0	4.3	0.0	4.7	3.5	2.9	16.0	16.9	6.0	4.0	8.1	6.3	5.3	3.4	7.1	9.4	13.2	6.2	3.7	10.8	8.7	12.8	5.4
27	6.6	11.7	1.3	10.3	5.0	1.0	12.8	9.9	11.5	4.6	18.6	10.0	6.6	6.6	9.4	15.6	0.4	14.8	14.2	8.7	3.0	14.3	3.7	7.7	7.7	4.7	0.0	10.1	6.3	16.7	17.4	1.3	7.3	14.1	7.0	8.5	8.3	4.6	14.0	17.8	9.3	2.1	14.5	12.2	16.2	3.1
28	6.1	4.7	7.1	4.0	13.7	11.1	6.6	2.1	8.6	11.0	13.9	4.3	8.3	2.3	2.5	11.0	8.0	8.4	9.7	0.4	5.8	10.7	9.6	5.5	6.8	3.5	10.1	0.0	8.0	9.8	10.6	11.6	9.0	6.4	5.0	10.2	1.8	12.4	14.2	11.2	11.0	7.3	10.9	8.6	12.7	8.9
29	5.6	8.9	4.9	7.8	8.7	5.3	11.1	8.3	6.6	8.5	14.3	8.1	1.8	4.8	5.2	11.1	5.9	8.3	8.1	8.5	3.5	9.3	7.5	2.7	1.5	2.9	6.3	8.0	0.0	16.4	17.2	7.6	0.9	9.3	11.0	2.2	6.3	8.6	6.2	13.4	3.1	5.4	9.3	7.1	11.1	7.1
30	16.6	14.4	20.8	13.1	24.2	17.9	9.6	11.8	7.6	23.7	15.6	13.9	14.7	10.3	7.2	7.9	16.8	6.0	12.2	12.1	15.4	7.5	19.2	11.6	15.9	16.0	16.7	9.8	16.4	0.0	2.5	19.2	12.2	5.5	15.2	13.3	8.2	18.6	17.3	3.0	14.2	15.3	9.6	11.5	12.0	17.2
31	14.8	15.8	18.7	9.4	25.0	18.6	10.4	12.7	8.4	24.2	16.2	14.6	16.0	11.0	7.8	8.8	17.5	6.8	12.9	12.9	16.1	8.2	19.9	12.4	16.7	16.9	17.4	10.6	17.2	2.5	0.0	19.1	12.9	6.1	16.0	14.1	9.4	19.4	18.3	4.0	15.0	16.2	1.4	12.6	12.8	18.0
32	6.0	12.9	3.0	11.8	4.8	2.3	14.0	11.9	13.1	4.3	19.9	11.2	7.9	7.9	10.9	17.1	1.6	16.0	15.5	10.1	4.3	15.6	3.5	8.7	9.0	6.0	1.3	11.6	7.6	19.2	19.1	0.0	8.6	14.1	6.3	9.9	9.5	4.3	13.9	19.4	10.8	3.7	15.7	14.3	17.3	2.6
33	6.5	9.8	5.0	7.7	9.6	6.5	8.7	9.4	7.8	10.8	13.3	9.0	4.3	7.2	4.9	12.3	7.0	10.4	7.0	8.0	4.7	10.4	8.7	2.5	1.1	4.0	7.3	9.0	0.9	12.2	12.9	8.6	0.0	9.2	9.5	1.4	6.1	9.4	5.3	13.4	2.2	6.3	12.7	7.1	10.9	7.8
34	10.4	11.6	11.3	5.1	16.4	12.7	6.3	8.5	2.1	15.1	10.8	10.6	9.5	6.9	3.8	4.5	12.7	2.0	7.0	6.9	10.2	4.2	15.3	6.4	8.0	8.1	14.1	6.4	9.3	5.5	6.1	14.1	9.2	0.0	11.8	9.8	4.8	14.9	11.3	5.2	10.6	11.7	4.9	6.3	7.3	13.4
35	4.8	2.5	5.9	9.1	7.7	6.0	11.6	7.3	13.8	7.3	19.0	2.0	10.0	4.9	8.0	16.1	6.8	13.5	14.7	5.3	7.4	15.8	3.4	10.6	12.5	6.3	7.0	5.0	11.0	15.2	16.0	6.3	9.5	11.8	0.0	13.3	6.8	7.6	17.4	15.9	14.2	16.3	7.2	13.9	17.9	3.8
36	7.6	12.1	6.2	8.8	11.0	7.7	9.8	10.6	9.0	11.9	12.2	10.1	5.5	8.4	6.1	13.4	8.2	11.6	5.8	9.1	5.9	11.6	9.8	3.8	2.3	5.3	8.5	10.2	2.2	13.3	14.1	9.9	1.4	9.8	13.3	0.0	7.3	10.5	4.1	14.3	0.8	7.4	11.3	5.4	9.3	9.1
37	7.7	6.7	6.5	2.3	10.6	10.0	4.8	3.6	6.9	10.3	12.3	5.7	6.5	2.1	1.1	9.2	8.0	6.7	7.8	2.0	5.5	9.0	8.0	3.9	5.2	3.4	8.3	1.8	6.3	8.2	9.4	9.5	6.1	4.8	6.8	7.3	0.0	9.8	12.4	9.4	9.2	7.1	13.4	7.2	11.1	8.9
38	6.3	9.8	3.5	12.6	2.3	3.5	15.1	7.0	13.7	2.0	21.0	10.3	8.8	9.1	12.1	18.9	4.2	18.7	14.9	10.7	5.0	16.3	4.0	9.6	9.9	7.1	4.6	12.4	8.6	18.6	19.4	4.3	9.4	14.9	7.6	10.5	9.8	0.0	14.8	20.4	11.6	4.4	19.7	13.8	17.9	3.3
39	11.7	17.1	11.1	13.1	14.9	10.7	13.9	14.7	12.8	15.8	11.4	13.2	9.6	12.5	10.4	17.6	12.2	13.5	5.3	13.1	9.9	15.8	13.9	7.9	6.4	9.4	14.0	14.2	6.2	17.3	18.3	13.9	5.3	11.3	17.4	4.1	12.4	14.8	0.0	16.1	3.2	11.5	8.7	5.1	8.9	13.2
40	14.9	15.3	17.3	10.1	21.2	17.7	10.8	12.8	10.0	20.8	12.5	14.8	13.9	11.4	8.3	5.0	17.8	2.9	13.2	11.1	16.6	4.6	20.2	10.8	13.1	13.2	17.8	11.2	13.4	3.0	4.0	19.4	13.4	5.2	15.9	14.3	9.4	20.4	16.1	0.0	15.6	8.7	8.7	14.6	11.1	19.5
41	8.5	13.0	8.0	9.7	11.8	8.5	14.1	11.4	8.5	12.7	11.3	11.0	6.4	9.3	7.1	14.3	9.1	12.4	5.0	10.0	6.7	12.4	10.7	4.6	3.0	6.2	9.3	11.0	3.1	14.2	15.0	10.8	2.2	10.6	14.2	0.8	9.2	11.6	3.2	15.6	0.0	8.5	8.1	4.8	8.5	9.9
42	6.0	9.8	0.9	9.2	4.8	1.2	12.0	9.2	10.6	3.5	17.4	8.9	5.4	5.7	8.6	14.9	1.8	13.8	13.3	7.7	1.8	13.4	3.6	6.4	6.7	3.7	2.0	7.3	5.4	15.3	16.2	3.7	6.3	11.7	16.3	7.4	7.1	4.4	11.5	8.7	8.5	0.0	12.7	10.7	14.5	3.1
43	12.9	16.2	12.5	9.2	20.3	12.6	16.9	12.7	2.3	20.2	3.4	15.2	9.6	16.7	12.1	5.9	17.0	6.5	4.4	15.1	11.4	4.2	15.7	6.5	8.2	10.8	14.5	10.9	9.3	9.6	1.4	15.7	12.7	4.9	7.2	11.3	13.4	19.7	8.7	8.7	8.1	12.7	0.0	3.7	2.3	15.0
44	11.1	18.8	10.6	8.8	14.4	10.8	10.1	10.6	4.0	13.8	7.0	14.6	7.5	10.5	6.0	12.4	13.7	8.3	0.8	8.8	9.1	6.8	13.3	4.6	6.0	8.7	12.2	8.6	7.1	11.5	12.6	14.3	7.1	6.3	13.9	5.4	7.2	13.8	5.1	14.6	4.8	10.7	3.7	0.0	4.1	12.6
45	15.0	22.9	14.5	12.7	18.3	14.8	13.7	14.5	4.8	18.0	3.0	18.6	11.4	14.2	9.8	8.4	15.7	8.9	3.5	12.6	13.0	6.5	17.3	8.6	10.0	12.8	16.2	12.7	11.1	12.0	12.8	17.3	10.9	7.3	17.9	9.3	11.1	17.9	8.9	11.1	8.5	14.5	2.3	4.1	0.0	17.1
46	3.1	6.4	2.1	10.9	3.7	2.2	13.5	11.0	12.4	3.4	19.5	5.6	7.4	7.8	10.7	17.4	2.7	15.4	13.2	12.6	3.5	15.1	0.6	8.1	8.6	5.4	3.1	8.9	7.1	17.2	18.0	2.9	7.8	13.4	3.8	9.1	8.9	3.3	13.2	19.5	9.9	3.1	15.0	12.6	17.1	0.0

Table H.2: Shortest distance matrix of Nellikudur mandal in link failure condition

O/D	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46
1	0.0	4.5	5.1	4.5	6.9	5.1	12.5	9.3	11.0	6.4	16.2	3.7	5.6	4.5	7.2	14.6	6.1	12.7	11.5	6.2	4.6	13.4	2.5	6.7	6.7	2.6	6.6	6.1	5.6	16.6	14.8	6.0	6.5	10.4	4.8	7.6	7.7	6.3	11.7	14.9	8.5	6.0	12.9	11.1	15.0	3.1
2	4.5	0.0	9.2	4.9	10.1	9.4	5.9	6.7	14.3	12.8	26.1	0.7	10.1	4.9	7.8	15.8	11.3	13.5	19.4	5.0	9.7	16.8	5.3	14.5	11.6	5.7	11.7	4.7	8.9	14.4	15.8	12.9	9.8	11.6	2.5	12.1	6.7	9.8	17.1	15.3	13.0	9.8	16.2	18.8	22.9	6.4
3	5.1	9.2	0.0	8.9	4.0	0.3	13.1	9.2	10.4	3.7	17.9	9.2	5.2	5.6	7.5	15.4	1.0	14.5	11.2	7.4	1.4	13.0	2.6	6.1	6.5	3.3	1.3	7.1	4.9	20.8	18.7	3.0	5.0	11.3	5.9	6.2	6.5	3.5	11.1	17.3	8.0	0.9	12.5	10.6	14.5	2.1
4	4.5	4.9	8.9	0.0	12.8	9.1	5.3	5.9	7.2	12.5	12.5	8.5	8.7	4.3	2.6	9.1	9.4	6.9	11.3	4.3	7.5	9.2	9.6	5.1	6.5	5.5	10.3	4.0	7.8	13.1	9.4	11.8	7.7	5.1	9.1	8.8	4.9	12.6	13.1	10.1	9.7	9.2	9.2	8.8	12.7	10.9
5	6.9	10.1	4.0	12.8	0.0	3.9	16.9	15.7	14.1	1.5	19.8	9.4	9.2	11.4	12.4	18.4	5.0	18.3	15.1	14.0	5.3	16.6	4.3	9.9	10.2	7.4	5.0	13.7	8.7	24.2	25.0	4.8	9.6	16.4	7.7	11.0	10.6	2.3	14.9	21.2	11.8	4.8	20.3	14.4	18.3	3.7
6	5.1	9.4	1.9	9.1	3.9	0.0	12.9	9.2	10.7	3.7	18.2	9.2	5.7	9.2	8.9	15.2	0.7	14.6	11.1	14.4	1.7	13.5	2.7	8.3	6.9	3.8	1.1	11.1	5.3	17.9	18.6	2.5	6.5	12.7	6.0	7.7	10.0	3.5	10.7	17.7	8.5	1.2	12.6	10.8	14.8	2.2
7	12.5	5.9	13.1	5.3	16.9	12.9	0.0	8.5	8.3	15.3	16.4	10.8	11.5	7.1	3.9	10.6	11.9	8.3	10.4	6.9	10.1	10.5	14.1	6.2	7.6	8.3	12.8	6.6	11.1	9.6	10.4	14.0	8.7	6.3	11.6	9.8	4.8	15.1	13.9	10.8	14.1	12.0	16.9	10.1	13.7	13.5
8	9.3	6.7	9.2	5.9	15.7	9.2	8.5	0.0	10.6	16.8	17.8	8.5	10.1	4.3	4.6	12.7	9.9	10.4	11.4	4.5	7.5	12.7	11.5	7.1	9.7	5.4	9.9	2.1	8.3	11.8	12.7	11.9	9.4	8.5	7.3	10.6	3.6	7.0	14.7	12.8	11.4	9.2	12.7	10.6	14.5	11.0
9	3.9	14.3	10.4	7.2	14.1	10.7	8.3	10.6	0.0	14.0	5.6	13.5	7.2	10.2	5.8	4.4	11.3	5.0	4.5	8.6	8.9	2.6	13.0	4.2	5.5	8.3	11.5	8.6	6.6	7.6	8.4	13.1	7.8	2.1	13.8	9.0	6.9	13.7	12.8	10.0	8.5	10.6	2.3	4.0	4.8	12.4
10	6.4	12.8	3.7	12.5	3.4	3.7	15.3	16.8	14.0	0.0	19.3	9.2	8.8	9.1	12.3	18.0	4.3	18.5	14.6	11.1	5.0	16.2	4.2	9.6	9.7	7.0	4.6	11.0	8.5	23.7	24.2	4.3	10.8	15.1	7.3	11.9	10.3	2.0	15.8	20.8	12.7	3.5	20.2	13.8	18.0	3.4
11	16.2	26.1	17.9	12.5	19.8	18.2	16.4	17.8	5.6	19.3	0.0	18.1	14.3	15.6	11.3	8.7	17.5	9.3	6.6	14.3	16.0	7.0	18.8	15.9	14.4	15.4	18.6	13.9	14.3	15.6	16.2	19.9	13.3	10.8	19.0	12.2	12.3	21.0	11.4	12.5	11.3	17.4	3.4	7.0	4.6	19.5
12	3.7	3.7	9.2	8.5	9.4	9.2	10.8	8.5	13.5	9.2	18.1	0.0	9.1	4.1	6.9	14.8	9.5	12.5	14.4	4.7	7.2	14.7	5.1	10.0	10.2	5.2	10.0	4.3	8.1	13.9	14.6	11.2	9.0	10.6	1.8	10.1	5.7	10.3	13.2	14.8	11.0	8.9	15.2	14.6	18.6	5.6
13	5.6	10.1	5.2	8.7	9.2	5.7	11.5	10.1	7.2	8.8	14.3	9.1	0.0	5.2	5.6	13.7	6.2	11.5	8.1	8.6	3.8	13.7	8.0	3.0	3.3	3.3	6.6	8.3	1.8	14.7	16.0	7.9	4.3	9.5	10.0	5.5	6.5	8.8	9.6	13.9	6.4	5.4	9.6	7.5	11.4	7.4
14	4.5	4.9	5.6	4.3	11.4	9.2	7.1	4.3	10.2	9.1	15.6	4.1	5.2	0.0	3.2	11.1	6.2	8.8	11.0	2.4	4.0	11.0	8.4	6.0	6.3	2.0	6.6	2.3	4.8	10.3	11.0	7.9	7.2	6.9	4.9	8.4	2.1	9.1	12.5	11.4	9.3	5.7	16.7	10.5	14.2	7.8
15	7.2	7.8	7.5	3.9	12.4	8.9	3.9	4.6	5.8	12.3	11.3	6.9	5.6	3.2	0.0	8.1	8.8	5.8	6.6	3.0	7.2	8.0	11.2	2.6	3.8	6.5	9.4	2.7	5.2	7.2	7.8	10.9	4.9	3.8	8.0	6.1	1.1	12.1	10.4	8.3	7.1	8.6	12.1	6.0	9.8	10.7
16	14.6	15.8	15.4	9.1	18.4	15.2	10.6	12.7	4.4	18.0	8.7	14.8	13.7	11.1	8.1	0.0	14.9	2.5	11.7	11.4	13.2	8.3	17.8	8.5	9.9	12.6	15.6	11.0	11.1	7.9	8.8	17.1	12.3	4.5	16.1	13.4	9.2	18.9	17.6	5.0	14.3	14.9	5.9	12.4	8.4	17.4
17	6.1	11.3	1.0	9.4	5.0	0.7	11.9	9.9	11.3	4.3	17.5	9.5	6.2	6.2	8.8	14.9	0.0	14.7	12.3	8.2	2.4	17.0	3.3	7.2	7.5	4.6	0.4	8.0	5.9	16.8	17.5	1.6	7.0	12.7	6.8	8.2	8.0	4.2	12.2	17.8	9.1	1.8	17.0	13.7	15.7	2.7
18	12.7	13.5	14.5	6.9	18.3	14.6	8.3	10.4	5.0	18.5	9.3	12.5	11.5	8.8	5.8	2.5	14.7	0.0	9.0	8.6	12.1	2.4	14.8	8.0	9.3	10.0	14.8	8.4	8.3	6.0	6.8	16.0	10.4	2.0	13.5	11.6	6.7	18.7	13.5	2.9	12.4	13.8	6.5	8.3	8.9	15.4
19	11.5	19.4	11.2	11.3	15.1	11.1	10.4	11.4	4.5	14.6	6.6	14.4	8.1	11.0	6.6	11.7	12.3	9.0	0.0	10.0	11.4	7.3	13.9	5.1	8.0	11.0	14.2	9.7	8.1	12.2	12.9	15.5	7.0	7.0	14.7	5.8	7.8	14.9	5.3	13.2	5.0	13.3	4.4	0.8	3.5	13.2
20	6.2	5.0	7.4	4.3	14.0	14.4	6.9	5.4	8.6	11.1	14.3	4.7	8.6	2.4	3.0	11.4	8.2	8.6	10.0	0.0	5.9	11.1	9.8	5.5	6.8	3.8	8.7	0.4	8.5	12.1	12.9	10.1	8.0	6.9	5.3	9.1	2.0	10.7	13.1	11.1	10.0	7.7	15.1	8.8	12.6	9.3
21	4.6	9.7	1.4	7.5	5.3	1.7	10.1	7.5	8.9	5.0	16.0	7.2	3.8	4.0	7.2	13.2	2.4	12.1	11.4	5.9	0.0	11.5	4.0	4.8	5.1	2.2	3.0	5.8	3.5	15.4	16.1	4.3	4.7	10.2	7.4	5.9	5.5	5.0	9.9	16.6	6.7	1.8	11.4	9.1	13.0	3.5
22	13.4	16.8	13.0	9.2	16.6	13.5	10.5	12.7	2.6	16.2	7.0	14.7	13.7	11.0	8.0	1.8	17.0	2.4	7.3	11.1	11.5	0.0	15.6	6.7	8.0	10.9	14.3	10.7	9.3	7.5	8.2	15.6	10.4	4.2	15.8	11.6	9.0	16.3	15.8	4.6	12.4	13.4	4.2	6.8	6.5	15.1
23	2.5	5.3	2.6	9.6	4.3	2.7	14.1	11.5	13.0	6.0	18.8	5.1	8.0	8.4	11.2	17.8	3.3	14.8	13.9	9.8	4.0	15.6	0.0	8.7	9.1	4.7	3.7	9.6	7.5	19.2	19.9	3.5	8.7	15.3	3.4	9.8	8.0	4.0	13.9	20.2	10.7	3.6	15.7	13.3	17.3	0.6

O/D	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46
24	6.7	14.5	6.1	5.1	9.9	8.3	6.2	7.1	4.2	9.6	15.9	10.0	3.0	6.0	2.6	8.5	7.2	8.0	5.1	5.5	4.8	6.7	8.7	0.0	1.5	4.0	7.7	5.5	2.7	11.6	12.4	8.7	2.5	6.4	10.6	3.8	3.9	9.6	7.9	10.8	4.6	6.4	6.5	4.6	8.6	8.1
25	6.7	11.6	6.5	6.5	10.2	6.9	7.6	9.7	5.5	9.7	14.4	10.2	3.3	6.3	3.8	9.9	7.5	9.3	8.0	6.8	5.1	8.0	9.1	1.5	0.0	4.3	7.7	6.8	1.5	15.9	16.7	9.0	1.1	8.0	12.5	2.3	5.2	9.9	6.4	13.1	3.1	6.7	8.2	6.0	10.0	8.6
26	2.6	5.7	3.3	5.5	7.4	3.8	8.3	5.4	8.3	7.0	15.4	5.2	3.3	4.5	6.5	12.6	4.6	10.0	11.0	3.8	2.2	10.9	4.7	4.0	4.3	0.0	4.7	3.5	2.9	16.0	16.9	6.0	4.0	8.1	6.3	5.3	3.4	7.1	9.4	13.2	6.2	3.7	10.8	8.7	12.8	5.4
27	6.6	11.7	1.3	10.3	5.0	1.0	12.8	9.9	11.5	4.6	18.6	10.0	6.6	6.6	9.4	15.6	0.4	14.8	14.2	8.7	3.0	14.3	3.7	7.7	7.7	4.7	0.0	10.1	6.3	16.7	17.4	1.3	7.3	14.1	7.0	8.5	8.3	4.6	14.0	17.8	9.3	2.1	14.5	12.2	16.2	3.1
28	6.1	4.7	7.1	4.0	13.7	11.1	6.6	2.1	8.6	11.0	13.9	4.3	8.3	2.3	5.6	11.0	8.0	8.4	9.7	0.4	5.8	10.7	9.6	5.5	6.8	3.5	10.1	0.0	8.0	9.8	10.6	11.6	9.0	6.4	5.0	10.2	1.8	12.4	14.2	11.2	11.0	7.3	10.9	8.6	12.7	8.9
29	5.6	8.9	4.9	7.8	8.7	5.3	11.1	8.3	6.6	8.5	14.3	8.1	1.8	4.8	5.2	11.1	5.9	8.3	8.1	8.5	3.5	9.3	7.5	2.7	1.5	2.9	6.3	8.0	0.0	16.4	17.2	7.6	0.9	9.3	11.0	2.2	6.3	8.6	6.2	13.4	3.1	5.4	9.3	7.1	11.1	7.1
30	16.6	14.4	20.8	13.1	24.2	17.9	9.6	11.8	7.6	23.7	15.6	13.9	14.7	10.3	7.2	7.9	16.8	6.0	12.2	12.1	15.4	7.5	19.2	11.6	15.9	16.0	16.7	9.8	16.4	0.0	2.5	19.2	12.2	5.5	15.2	13.3	8.2	18.6	17.3	3.0	14.2	15.3	9.6	11.5	12.0	17.2
31	14.8	15.8	18.7	9.4	25.0	18.6	10.4	12.7	8.4	24.2	16.2	14.6	16.0	11.0	7.8	8.8	17.5	6.8	12.9	12.9	16.1	8.2	19.9	12.4	16.7	16.9	17.4	10.6	17.2	2.5	0.0	19.1	12.9	6.1	16.0	14.1	9.4	19.4	18.3	4.0	15.0	16.2	1.4	12.6	12.8	18.0
32	6.0	12.9	3.0	11.8	4.8	2.3	14.0	11.9	13.1	4.3	19.9	11.2	7.9	7.9	10.9	17.1	1.6	16.0	15.5	10.1	4.3	15.6	3.5	8.7	9.0	6.0	1.3	11.6	7.6	19.2	19.1	0.0	8.6	14.1	6.3	9.9	9.5	4.3	13.9	19.4	10.8	3.7	15.7	14.3	17.3	6.5
33	6.5	9.8	5.0	7.7	9.6	6.5	8.7	9.4	7.8	10.8	13.3	9.0	4.3	7.2	4.9	12.3	7.0	10.4	7.0	8.0	4.7	10.4	8.7	2.5	1.1	4.0	7.3	9.0	0.9	12.2	12.9	8.6	0.0	9.2	9.5	1.4	6.1	9.4	5.3	13.4	2.2	6.3	12.7	7.1	10.9	7.8
34	10.4	11.6	11.3	5.1	16.4	12.7	6.3	8.5	2.1	15.1	10.8	10.6	9.5	6.9	3.8	4.5	12.7	2.0	7.0	6.9	10.2	4.2	15.3	6.4	8.0	8.1	14.1	6.4	9.3	5.5	6.1	14.1	9.2	0.0	11.8	9.8	4.8	14.9	11.3	5.2	10.6	11.7	4.9	6.3	7.3	13.4
35	4.8	2.5	5.9	9.1	7.7	6.0	11.6	7.3	13.8	7.3	19.0	5.4	10.0	4.9	8.0	16.1	6.8	13.5	14.7	5.3	7.4	15.8	3.4	10.6	12.5	6.3	7.0	5.0	11.0	15.2	16.0	6.3	9.5	11.8	0.0	13.3	6.8	7.6	17.4	15.9	14.2	16.3	7.2	13.9	17.9	3.8
36	7.6	12.1	6.2	8.8	11.0	7.7	9.8	10.6	9.0	11.9	12.2	10.1	5.5	8.4	6.1	13.4	8.2	11.6	5.8	9.1	5.9	11.6	9.8	3.8	2.3	5.3	8.5	10.2	2.2	13.3	14.1	9.9	1.4	9.8	13.3	0.0	7.3	10.5	4.1	14.3	0.8	7.4	11.3	5.4	9.3	9.1
37	7.7	6.7	6.5	2.3	10.6	10.0	4.8	3.6	6.9	10.3	12.3	5.7	6.5	2.1	1.1	9.2	8.0	6.7	7.8	2.0	5.5	9.0	8.0	3.9	5.2	3.4	8.3	1.8	6.3	8.2	9.4	9.5	6.1	4.8	6.8	7.3	0.0	9.8	12.4	9.4	9.2	7.1	13.4	7.2	11.1	8.9
38	6.3	9.8	3.5	12.6	2.3	3.5	15.1	7.0	13.7	2.0	21.0	10.3	8.8	9.1	12.1	18.9	4.2	18.7	14.9	10.7	5.0	16.3	4.0	9.6	9.9	7.1	4.6	12.4	8.6	18.6	19.4	4.3	9.4	14.9	7.6	10.5	9.8	0.0	14.8	20.4	11.6	4.4	19.7	13.8	17.9	3.3
39	11.7	17.1	11.1	13.1	14.9	10.7	13.9	14.7	12.8	15.8	11.4	13.2	9.6	12.5	10.4	17.6	12.2	13.5	5.3	13.1	9.9	15.8	13.9	7.9	6.4	9.4	14.0	14.2	6.2	17.3	18.3	13.9	5.3	11.3	17.4	4.1	12.4	14.8	0.0	16.1	3.2	11.5	8.7	5.1	8.9	13.2
40	14.9	15.3	17.3	10.1	21.2	17.7	10.8	12.8	10.0	20.8	12.5	14.8	13.9	11.4	8.3	5.0	17.8	2.9	13.2	11.1	16.6	4.6	20.2	10.8	13.1	13.2	17.8	11.2	13.4	3.0	4.0	19.4	13.4	5.2	15.9	14.3	9.4	20.4	16.1	0.0	15.6	8.7	8.7	14.6	11.1	19.5
41	8.5	13.0	8.0	9.7	11.8	8.5	14.1	11.4	8.5	12.7	11.3	11.0	6.4	9.3	7.1	14.3	9.1	12.4	5.0	10.0	6.7	12.4	10.7	4.6	9.6	6.2	9.3	11.0	3.1	14.2	15.0	10.8	2.2	10.6	14.2	0.8	9.2	11.6	3.2	15.6	0.0	8.5	8.1	4.8	8.5	9.9
42	6.0	9.8	0.9	9.2	4.8	1.2	12.0	9.2	10.6	3.5	17.4	8.9	5.4	5.7	8.6	14.9	1.8	13.8	13.3	7.7	1.8	13.4	3.6	6.4	6.7	3.7	2.6	7.3	5.4	15.3	16.2	3.7	6.3	11.7	16.3	7.4	7.1	4.4	11.5	8.7	8.5	0.0	12.7	10.7	14.5	3.1
43	12.9	16.2	12.5	9.2	20.3	12.6	16.9	12.7	2.3	20.2	3.4	15.2	9.6	16.7	12.1	5.9	17.0	6.5	4.4	15.1	11.4	4.2	15.7	6.5	8.2	10.8	14.5	10.9	9.3	9.6	1.4	15.7	12.7	4.9	7.2	11.3	13.4	19.7	8.7	8.7	8.1	12.7	0.0	3.7	2.3	15.0
44	11.1	18.8	10.6	8.8	14.4	10.8	10.1	10.6	4.0	13.8	7.0	14.6	7.5	10.5	6.0	12.4	13.7	8.3	0.8	8.8	9.1	6.8	13.3	4.6	6.0	8.7	12.2	8.6	7.1	11.5	12.6	14.3	7.1	6.3	13.9	5.4	7.2	13.8	5.1	14.6	4.8	10.7	3.7	0.0	4.1	12.6
45	15.0	22.9	14.5	12.7	18.3	14.8	13.7	14.5	4.8	18.0	8.0	18.6	11.4	14.2	9.8	8.4	15.7	8.9	3.5	12.6	13.0	6.5	17.3	8.6	10.0	12.8	16.2	12.7	11.1	12.0	12.8	17.3	10.9	7.3	17.9	9.3	11.1	17.9	8.9	11.1	8.5	14.5	2.3	4.1	0.0	17.1
46	3.1	6.4	3.3	10.9	3.7	2.2	13.5	11.0	12.4	3.4	19.5	5.6	7.4	7.8	10.7	17.4	2.7	15.4	13.2	12.6	3.5	15.1	0.6	8.1	8.6	5.4	3.1	8.9	7.1	17.2	18.0	2.9	7.8	13.4	3.8	9.1	8.9	3.3	13.2	19.5	9.9	3.1	15.0	12.6	17.1	0.0

Table H.3: Accessibility value of the links in normal condition

O/D	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46
1	-	0.063	0.047	0.051	0.038	0.037	0.014	0.028	0.020	0.038	0.016	0.070	0.069	0.057	0.039	0.016	0.044	0.019	0.023	0.046	0.053	0.024	0.113	0.039	0.049	0.110	0.032	0.048	0.064	0.014	0.016	0.038	0.043	0.022	0.050	0.034	0.031	0.045	0.032	0.019	0.031	0.038	0.046	0.027	0.019	0.127
2	0.058	-	0.026	0.047	0.026	0.020	0.029	0.039	0.015	0.019	0.010	0.361	0.039	0.053	0.036	0.015	0.024	0.018	0.013	0.056	0.025	0.019	0.053	0.018	0.028	0.049	0.018	0.062	0.040	0.017	0.015	0.018	0.029	0.020	0.098	0.021	0.036	0.029	0.022	0.018	0.020	0.024	0.036	0.016	0.012	0.061
3	0.051	0.031	-	0.026	0.065	0.633	0.013	0.028	0.021	0.065	0.015	0.028	0.075	0.047	0.037	0.016	0.273	0.017	0.023	0.038	0.169	0.025	0.107	0.043	0.051	0.086	0.162	0.041	0.073	0.012	0.012	0.078	0.056	0.020	0.041	0.042	0.037	0.080	0.033	0.016	0.033	0.253	0.047	0.028	0.019	0.189
4	0.058	0.058	0.027	-	0.020	0.021	0.032	0.044	0.030	0.019	0.021	0.031	0.045	0.061	0.106	0.026	0.029	0.035	0.023	0.066	0.032	0.035	0.029	0.051	0.051	0.051	0.020	0.073	0.046	0.018	0.024	0.020	0.037	0.045	0.026	0.030	0.120	0.022	0.028	0.028	0.027	0.025	0.064	0.034	0.022	0.036
5	0.038	0.028	0.060	0.018	-	0.049	0.010	0.017	0.016	0.158	0.013	0.028	0.043	0.023	0.023	0.013	0.054	0.013	0.017	0.020	0.045	0.019	0.065	0.026	0.032	0.038	0.042	0.021	0.041	0.010	0.009	0.048	0.029	0.014	0.031	0.024	0.023	0.123	0.025	0.013	0.022	0.048	0.029	0.021	0.015	0.105
6	0.051	0.030	0.343	0.025	0.067	-	0.013	0.028	0.021	0.065	0.014	0.028	0.068	0.028	0.031	0.016	0.397	0.016	0.023	0.019	0.140	0.024	0.104	0.031	0.048	0.074	0.194	0.026	0.068	0.013	0.012	0.092	0.043	0.018	0.040	0.034	0.024	0.080	0.035	0.016	0.031	0.195	0.047	0.028	0.019	0.179
7	0.021	0.047	0.018	0.044	0.015	0.015	-	0.031	0.027	0.016	0.016	0.024	0.034	0.037	0.072	0.023	0.023	0.029	0.025	0.041	0.024	0.030	0.020	0.042	0.043	0.034	0.016	0.044	0.032	0.025	0.022	0.016	0.032	0.037	0.021	0.027	0.050	0.019	0.027	0.026	0.018	0.019	0.035	0.030	0.020	0.029
8	0.028	0.042	0.026	0.039	0.017	0.021	0.020	-	0.021	0.014	0.015	0.030	0.039	0.060	0.061	0.019	0.027	0.023	0.023	0.140	0.032	0.025	0.024	0.037	0.034	0.052	0.021	0.138	0.043	0.020	0.018	0.019	0.030	0.027	0.033	0.025	0.066	0.040	0.025	0.022	0.023	0.025	0.046	0.028	0.019	0.036
9	0.118	0.020	0.023	0.032	0.018	0.018	0.020	0.025	-	0.017	0.047	0.019	0.055	0.026	0.048	0.055	0.024	0.048	0.058	0.032	0.027	0.121	0.021	0.062	0.060	0.034	0.018	0.034	0.055	0.032	0.027	0.018	0.036	0.110	0.017	0.029	0.035	0.020	0.029	0.028	0.030	0.022	0.262	0.075	0.058	0.031
10	0.041	0.022	0.065	0.018	0.171	0.051	0.011	0.016	0.016	-	0.013	0.028	0.044	0.029	0.023	0.013	0.063	0.013	0.018	0.025	0.048	0.020	0.067	0.027	0.034	0.040	0.046	0.026	0.042	0.010	0.009	0.054	0.026	0.015	0.033	0.022	0.023	0.138	0.023	0.013	0.020	0.066	0.029	0.022	0.016	0.115
11	0.016	0.011	0.013	0.018	0.013	0.010	0.010	0.015	0.039	0.012	-	0.014	0.027	0.017	0.025	0.028	0.015	0.026	0.039	0.020	0.015	0.046	0.015	0.016	0.023	0.018	0.011	0.021	0.025	0.015	0.014	0.012	0.021	0.021	0.013	0.021	0.019	0.013	0.032	0.022	0.023	0.013	0.176	0.043	0.093	0.020
12	0.070	0.280	0.026	0.027	0.028	0.021	0.016	0.030	0.016	0.026	0.014	-	0.043	0.063	0.041	0.016	0.028	0.019	0.018	0.060	0.033	0.022	0.055	0.026	0.032	0.054	0.021	0.068	0.044	0.017	0.016	0.021	0.031	0.022	0.136	0.026	0.042	0.027	0.028	0.019	0.024	0.026	0.039	0.021	0.015	0.070
13	0.046	0.028	0.046	0.026	0.028	0.033	0.015	0.026	0.031	0.027	0.018	0.028	-	0.050	0.050	0.018	0.044	0.021	0.032	0.033	0.063	0.023	0.035	0.088	0.101	0.084	0.032	0.035	0.198	0.016	0.014	0.029	0.065	0.024	0.024	0.047	0.037	0.032	0.039	0.020	0.041	0.042	0.061	0.040	0.025	0.053
14	0.057	0.057	0.043	0.054	0.023	0.021	0.024	0.060	0.022	0.026	0.017	0.063	0.075	-	0.089	0.022	0.043	0.027	0.024	0.115	0.061	0.029	0.033	0.043	0.053	0.140	0.032	0.127	0.075	0.023	0.021	0.029	0.039	0.033	0.049	0.031	0.112	0.031	0.030	0.025	0.028	0.040	0.035	0.029	0.020	0.050
15	0.036	0.036	0.032	0.092	0.021	0.021	0.044	0.057	0.038	0.020	0.023	0.038	0.070	0.082	-	0.030	0.031	0.041	0.040	0.094	0.033	0.040	0.025	0.101	0.088	0.043	0.022	0.109	0.069	0.033	0.030	0.021	0.057	0.061	0.030	0.043	0.211	0.023	0.036	0.034	0.037	0.027	0.049	0.050	0.029	0.036
16	0.018	0.018	0.016	0.025	0.014	0.013	0.016	0.020	0.051	0.013	0.030	0.018	0.028	0.023	0.035	-	0.018	0.098	0.022	0.025	0.018	0.160	0.016	0.031	0.033	0.022	0.013	0.026	0.032	0.030	0.026	0.013	0.023	0.051	0.015	0.019	0.026	0.015	0.021	0.056	0.018	0.015	0.099	0.024	0.033	0.022
17	0.042	0.025	0.242	0.024	0.052	0.279	0.014	0.026	0.020	0.056	0.015	0.027	0.063	0.042	0.032	0.016	-	0.016	0.021	0.034	0.098	0.019	0.086	0.036	0.044	0.061	0.583	0.036	0.061	0.014	0.013	0.142	0.040	0.018	0.035	0.032	0.030	0.067	0.030	0.016	0.029	0.130	0.035	0.022	0.018	0.143
18	0.021	0.021	0.017	0.033	0.014	0.013	0.020	0.025	0.044	0.013	0.028	0.021	0.034	0.030	0.048	0.098	0.018	-	0.029	0.033	0.020	0.133	0.019	0.032	0.035	0.028	0.014	0.035	0.043	0.040	0.034	0.014	0.027	0.114	0.018	0.022	0.036	0.015	0.027	0.096	0.021	0.017	0.091	0.036	0.032	0.025
19	0.023	0.014	0.021	0.020	0.017	0.017	0.016	0.023	0.049	0.016	0.039	0.018	0.048	0.024	0.043	0.020	0.022	0.027	-	0.028	0.021	0.044	0.020	0.051	0.041	0.026	0.015	0.030	0.045	0.020	0.018	0.015	0.040	0.033	0.016	0.045	0.031	0.019	0.070	0.021	0.052	0.017	0.135	0.400	0.080	0.030
20	0.042	0.056	0.032	0.054	0.019	0.013	0.025	0.130	0.026	0.022	0.018	0.056	0.046	0.107	0.094	0.021	0.033	0.028	0.026	-	0.041	0.029	0.029	0.047	0.049	0.073	0.024	0.806	0.043	0.020	0.018	0.023	0.035	0.033	0.045	0.029	0.121	0.026	0.028	0.025	0.026	0.030	0.039	0.034	0.022	0.042
21	0.057	0.029	0.169	0.031	0.049	0.110	0.017	0.035	0.025	0.048	0.016	0.036	0.103	0.066	0.039	0.018	0.111	0.020	0.023	0.047	-	0.028	0.070	0.055	0.065	0.130	0.071	0.050	0.103	0.016	0.014	0.054	0.060	0.023	0.032	0.044	0.043	0.056	0.038	0.017	0.039	0.130	0.052	0.033	0.021	0.113
22	0.019	0.017	0.018	0.025	0.016	0.014	0.016	0.021	0.083	0.015	0.037	0.018	0.028	0.024	0.035	0.130	0.016	0.100	0.035	0.025	0.021	-	0.018	0.039	0.041	0.026	0.015	0.027	0.039	0.032	0.028	0.015	0.027	0.055	0.015	0.022	0.027	0.017	0.023	0.061	0.021	0.017	0.141	0.044	0.043	0.026
23	0.105	0.053	0.092	0.024	0.060	0.071	0.012	0.023	0.017	0.060	0.014	0.051	0.049	0.031	0.025	0.013	0.083	0.016	0.019	0.029	0.060	0.021	-	0.030	0.036	0.059	0.057	0.030	0.048	0.012	0.012	0.066	0.032	0.015	0.070	0.027	0.030	0.069	0.027	0.014	0.024	0.064	0.038	0.023	0.016	0.629
24	0.039	0.019	0.039	0.045	0.026	0.023	0.027	0.037	0.052	0.025	0.016	0.026	0.132	0.043	0.109	0.028	0.038	0.030	0.051	0.051	0.051	0.048	0.032	-	0.224	0.069	0.027	0.053	0.135	0.021	0.019	0.026	0.110	0.036	0.023	0.069	0.062	0.029	0.047	0.026	0.056	0.036	0.090	0.066	0.033	0.048
25	0.039	0.024	0.037	0.036	0.025	0.027	0.022	0.027	0.040	0.025	0.018	0.025	0.119	0.042	0.074	0.024	0.036	0.026	0.032	0.041	0.047	0.040	0.031	0.177	-	0.065	0.027	0.043	0.235	0.015	0.014	0.025	0.250	0.029	0.019	0.114	0.046	0.028	0.058	0.021	0.083	0.034	0.072	0.050	0.028	0.046

O/D	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46
26	0.102	0.049	0.073	0.042	0.035	0.050	0.020	0.048	0.027	0.034	0.017	0.050	0.117	0.130	0.043	0.019	0.059	0.024	0.024	0.073	0.112	0.029	0.059	0.065	0.076	-	0.045	0.084	0.125	0.015	0.014	0.039	0.070	0.028	0.038	0.049	0.071	0.040	0.039	0.021	0.042	0.062	0.055	0.034	0.022	0.073
27	0.039	0.024	0.185	0.022	0.052	0.190	0.013	0.026	0.019	0.052	0.014	0.026	0.059	0.039	0.030	0.015	0.750	0.016	0.018	0.032	0.081	0.022	0.076	0.034	0.043	0.059	-	0.029	0.057	0.014	0.013	0.183	0.038	0.016	0.035	0.031	0.029	0.061	0.026	0.016	0.028	0.107	0.041	0.025	0.017	0.128
28	0.043	0.060	0.034	0.058	0.019	0.017	0.026	0.124	0.026	0.022	0.019	0.061	0.047	0.114	0.112	0.022	0.034	0.029	0.027	0.778	0.042	0.030	0.029	0.047	0.049	0.081	0.021	-	0.045	0.024	0.022	0.020	0.031	0.036	0.048	0.026	0.137	0.023	0.026	0.025	0.024	0.032	0.054	0.035	0.022	0.044
29	0.046	0.031	0.049	0.030	0.030	0.036	0.015	0.031	0.033	0.028	0.018	0.032	0.214	0.054	0.054	0.022	0.046	0.029	0.032	0.033	0.069	0.034	0.037	0.097	0.216	0.097	0.033	0.036	-	0.015	0.013	0.030	0.311	0.025	0.022	0.117	0.038	0.033	0.059	0.021	0.085	0.043	0.063	0.042	0.025	0.055
30	0.016	0.019	0.012	0.018	0.011	0.011	0.018	0.022	0.029	0.010	0.017	0.019	0.027	0.025	0.039	0.030	0.016	0.040	0.021	0.023	0.016	0.043	0.015	0.022	0.021	0.017	0.013	0.030	0.022	-	0.091	0.012	0.023	0.042	0.016	0.020	0.029	0.015	0.021	0.094	0.018	0.015	0.061	0.026	0.023	0.023
31	0.018	0.018	0.013	0.024	0.010	0.010	0.016	0.021	0.026	0.010	0.016	0.018	0.024	0.024	0.036	0.027	0.015	0.035	0.020	0.022	0.015	0.039	0.014	0.021	0.020	0.017	0.012	0.027	0.021	0.095	-	0.012	0.022	0.038	0.015	0.018	0.026	0.014	0.020	0.070	0.017	0.014	0.418	0.024	0.022	0.022
32	0.043	0.022	0.081	0.020	0.055	0.082	0.012	0.022	0.017	0.056	0.013	0.023	0.049	0.033	0.026	0.014	0.167	0.015	0.017	0.028	0.056	0.021	0.080	0.030	0.037	0.047	0.167	0.025	0.047	0.013	0.012	-	0.033	0.016	0.038	0.026	0.025	0.065	0.027	0.014	0.024	0.062	0.038	0.021	0.016	0.150
33	0.040	0.029	0.048	0.030	0.027	0.029	0.020	0.028	0.028	0.022	0.020	0.029	0.090	0.036	0.057	0.020	0.039	0.023	0.037	0.035	0.051	0.031	0.032	0.102	0.295	0.070	0.029	0.032	0.400	0.020	0.018	0.027	-	0.025	0.025	0.191	0.039	0.030	0.070	0.021	0.120	0.036	0.046	0.042	0.026	0.050
34	0.025	0.024	0.021	0.045	0.016	0.015	0.027	0.031	0.105	0.016	0.024	0.025	0.041	0.038	0.074	0.053	0.021	0.119	0.037	0.041	0.023	0.076	0.018	0.041	0.041	0.034	0.015	0.045	0.039	0.044	0.038	0.016	0.030	-	0.020	0.027	0.050	0.019	0.033	0.054	0.025	0.020	0.122	0.048	0.039	0.029
35	0.055	0.114	0.041	0.025	0.034	0.032	0.015	0.036	0.016	0.033	0.014	0.130	0.039	0.053	0.035	0.015	0.040	0.018	0.018	0.053	0.032	0.020	0.082	0.025	0.026	0.045	0.030	0.058	0.033	0.016	0.014	0.037	0.029	0.020	-	0.020	0.035	0.037	0.021	0.018	0.018	0.014	0.082	0.022	0.016	0.103
36	0.034	0.023	0.039	0.026	0.024	0.025	0.017	0.025	0.024	0.020	0.021	0.026	0.070	0.031	0.046	0.018	0.033	0.021	0.045	0.031	0.041	0.028	0.029	0.069	0.144	0.053	0.025	0.028	0.162	0.018	0.016	0.023	0.206	0.023	0.018	-	0.033	0.027	0.090	0.020	0.325	0.031	0.052	0.055	0.030	0.043
37	0.034	0.042	0.037	0.099	0.025	0.019	0.035	0.072	0.032	0.023	0.021	0.045	0.060	0.121	0.246	0.026	0.034	0.036	0.033	0.141	0.043	0.035	0.035	0.067	0.063	0.083	0.025	0.166	0.057	0.029	0.024	0.024	0.046	0.048	0.035	0.036	-	0.029	0.030	0.030	0.028	0.033	0.044	0.042	0.025	0.044
38	0.042	0.029	0.068	0.018	0.115	0.054	0.011	0.037	0.016	0.118	0.012	0.025	0.044	0.029	0.023	0.013	0.064	0.013	0.017	0.026	0.048	0.020	0.069	0.027	0.034	0.040	0.046	0.023	0.042	0.013	0.012	0.053	0.030	0.015	0.032	0.025	0.024	-	0.025	0.014	0.022	0.053	0.030	0.022	0.016	0.117
39	0.022	0.016	0.022	0.018	0.017	0.018	0.012	0.018	0.017	0.015	0.023	0.020	0.041	0.021	0.027	0.014	0.022	0.018	0.049	0.021	0.024	0.020	0.020	0.033	0.052	0.030	0.015	0.020	0.058	0.014	0.013	0.017	0.053	0.020	0.014	0.063	0.019	0.019	-	0.017	0.081	0.020	0.068	0.058	0.031	0.029
40	0.017	0.018	0.014	0.023	0.012	0.011	0.016	0.020	0.022	0.012	0.021	0.018	0.028	0.023	0.034	0.048	0.015	0.082	0.020	0.025	0.015	0.070	0.014	0.024	0.025	0.021	0.012	0.026	0.027	0.081	0.058	0.012	0.021	0.045	0.015	0.018	0.026	0.014	0.023	-	0.017	0.026	0.068	0.021	0.025	0.020
41	0.031	0.022	0.030	0.024	0.022	0.022	0.012	0.023	0.026	0.019	0.023	0.024	0.061	0.028	0.040	0.017	0.030	0.019	0.052	0.028	0.036	0.026	0.026	0.056	0.110	0.046	0.023	0.026	0.118	0.017	0.015	0.021	0.130	0.022	0.017	0.325	0.026	0.024	0.116	0.018	-	0.027	0.072	0.063	0.033	0.039
42	0.043	0.029	0.264	0.025	0.055	0.161	0.014	0.028	0.021	0.069	0.015	0.029	0.072	0.045	0.033	0.016	0.153	0.017	0.020	0.037	0.136	0.024	0.077	0.040	0.049	0.076	0.105	0.040	0.067	0.016	0.014	0.062	0.044	0.020	0.015	0.035	0.034	0.064	0.032	0.032	0.031	-	0.046	0.028	0.019	0.126
43	0.020	0.017	0.019	0.025	0.013	0.015	0.010	0.020	0.098	0.012	0.078	0.017	0.040	0.016	0.023	0.040	0.016	0.037	0.060	0.019	0.021	0.077	0.018	0.040	0.040	0.026	0.014	0.027	0.039	0.025	0.163	0.015	0.022	0.047	0.033	0.023	0.018	0.014	0.042	0.032	0.032	0.018	-	0.081	0.123	0.026
44	0.023	0.015	0.023	0.026	0.018	0.018	0.017	0.025	0.055	0.017	0.037	0.018	0.052	0.025	0.047	0.019	0.020	0.029	0.347	0.032	0.026	0.047	0.021	0.057	0.055	0.032	0.017	0.034	0.051	0.021	0.018	0.016	0.039	0.037	0.017	0.048	0.033	0.020	0.072	0.019	0.054	0.021	0.159	-	0.069	0.031
45	0.017	0.012	0.017	0.018	0.014	0.013	0.012	0.018	0.046	0.013	0.087	0.014	0.034	0.018	0.029	0.029	0.017	0.027	0.074	0.022	0.018	0.049	0.016	0.030	0.033	0.022	0.013	0.023	0.032	0.020	0.018	0.013	0.026	0.032	0.013	0.028	0.022	0.016	0.042	0.025	0.031	0.016	0.259	0.074	-	0.023
46	0.084	0.044	0.117	0.021	0.070	0.087	0.013	0.024	0.018	0.071	0.013	0.047	0.053	0.034	0.026	0.014	0.099	0.016	0.020	0.022	0.069	0.021	0.452	0.032	0.039	0.052	0.069	0.032	0.050	0.014	0.013	0.080	0.036	0.017	0.063	0.029	0.027	0.084	0.028	0.014	0.026	0.074	0.039	0.024	0.016	-

Table H.4: Accessibility value of the links in critical condition

O/D	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46
1	-	0.06	0.05	0.05	0.04	0.04	0.01	0.03	0.02	0.04	0.02	0.07	0.07	0.06	0.04	0.02	0.04	0.02	0.02	0.05	0.05	0.02	0.11	0.04	0.05	0.11	0.03	0.05	0.06	0.01	0.02	0.04	0.04	0.02	0.05	0.03	0.03	0.04	0.03	0.02	0.03	0.04	0.05	0.03	0.02	0.13
2	0.06	-	0.03	0.05	0.03	0.02	0.03	0.04	0.02	0.02	0.01	0.36	0.04	0.05	0.04	0.02	0.02	0.02	0.01	0.06	0.02	0.02	0.05	0.02	0.03	0.05	0.02	0.06	0.04	0.02	0.01	0.02	0.03	0.02	0.10	0.02	0.04	0.03	0.02	0.02	0.02	0.02	0.04	0.02	0.01	0.06
3	0.05	0.03	-	0.03	0.07	0.63	0.01	0.03	0.02	0.06	0.01	0.03	0.07	0.05	0.04	0.02	0.27	0.02	0.02	0.04	0.17	0.02	0.11	0.04	0.05	0.09	0.16	0.04	0.07	0.01	0.01	0.08	0.06	0.02	0.04	0.04	0.04	0.08	0.03	0.02	0.03	0.25	0.05	0.03	0.02	0.19
4	0.06	0.06	0.03	-	0.02	0.02	0.03	0.04	0.03	0.02	0.02	0.03	0.04	0.06	0.11	0.03	0.03	0.03	0.02	0.07	0.03	0.03	0.03	0.05	0.05	0.05	0.02	0.07	0.05	0.02	0.02	0.02	0.04	0.05	0.03	0.03	0.05	0.02	0.03	0.03	0.03	0.02	0.06	0.03	0.02	0.04
5	0.04	0.03	0.06	0.02	-	0.05	0.01	0.02	0.02	0.16	0.01	0.03	0.04	0.02	0.02	0.01	0.05	0.01	0.02	0.02	0.05	0.02	0.07	0.03	0.03	0.04	0.04	0.02	0.04	0.01	0.01	0.05	0.03	0.01	0.03	0.02	0.02	0.12	0.02	0.01	0.02	0.05	0.03	0.02	0.02	0.10
6	0.05	0.03	0.13	0.03	0.07	-	0.01	0.03	0.02	0.07	0.01	0.03	0.07	0.03	0.03	0.02	0.40	0.02	0.02	0.02	0.14	0.02	0.10	0.03	0.05	0.07	0.19	0.03	0.07	0.01	0.01	0.09	0.04	0.02	0.04	0.03	0.02	0.08	0.03	0.02	0.03	0.19	0.05	0.03	0.02	0.18
7	0.02	0.05	0.02	0.04	0.02	0.01	-	0.03	0.03	0.02	0.02	0.02	0.03	0.04	0.07	0.02	0.02	0.03	0.03	0.04	0.02	0.03	0.02	0.04	0.04	0.03	0.02	0.04	0.03	0.02	0.02	0.02	0.03	0.04	0.02	0.03	0.05	0.02	0.03	0.03	0.02	0.02	0.03	0.03	0.02	0.03
8	0.03	0.04	0.03	0.04	0.02	0.02	0.02	-	0.02	0.01	0.01	0.03	0.04	0.06	0.06	0.02	0.03	0.02	0.02	0.06	0.03	0.03	0.02	0.04	0.03	0.05	0.02	0.14	0.04	0.02	0.02	0.02	0.03	0.03	0.03	0.02	0.07	0.04	0.03	0.02	0.02	0.03	0.05	0.03	0.02	0.04
9	0.07	0.02	0.02	0.03	0.02	0.02	0.02	0.02	-	0.02	0.05	0.02	0.05	0.03	0.05	0.06	0.02	0.05	0.06	0.03	0.03	0.12	0.02	0.06	0.06	0.03	0.02	0.03	0.05	0.03	0.03	0.02	0.04	0.11	0.02	0.03	0.03	0.02	0.03	0.03	0.03	0.02	0.26	0.07	0.06	0.03
10	0.04	0.02	0.06	0.02	0.08	0.05	0.01	0.02	0.02	-	0.01	0.03	0.04	0.03	0.02	0.01	0.06	0.01	0.02	0.03	0.05	0.02	0.07	0.03	0.03	0.04	0.05	0.03	0.04	0.01	0.01	0.05	0.03	0.02	0.03	0.02	0.02	0.14	0.02	0.01	0.02	0.07	0.03	0.02	0.02	0.11
11	0.02	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.04	0.01	-	0.01	0.03	0.02	0.02	0.03	0.02	0.03	0.04	0.02	0.01	0.05	0.01	0.02	0.02	0.02	0.01	0.02	0.03	0.02	0.01	0.01	0.02	0.02	0.01	0.02	0.02	0.01	0.03	0.02	0.02	0.01	0.18	0.04	0.06	0.02
12	0.07	0.08	0.03	0.03	0.03	0.02	0.02	0.03	0.02	0.03	0.01	-	0.04	0.06	0.04	0.02	0.03	0.02	0.02	0.06	0.03	0.02	0.06	0.03	0.03	0.05	0.02	0.07	0.04	0.02	0.02	0.02	0.03	0.02	0.14	0.03	0.04	0.03	0.03	0.02	0.02	0.03	0.04	0.02	0.02	0.07
13	0.05	0.03	0.05	0.03	0.03	0.03	0.01	0.03	0.03	0.03	0.02	0.03	-	0.05	0.05	0.02	0.04	0.02	0.03	0.03	0.06	0.02	0.04	0.09	0.10	0.08	0.03	0.04	0.20	0.02	0.01	0.03	0.06	0.02	0.02	0.05	0.04	0.03	0.04	0.02	0.04	0.04	0.06	0.04	0.02	0.05
14	0.06	0.06	0.04	0.05	0.02	0.02	0.02	0.06	0.02	0.03	0.02	0.06	0.07	-	0.09	0.02	0.04	0.03	0.02	0.11	0.06	0.03	0.03	0.04	0.05	0.14	0.03	0.13	0.07	0.02	0.02	0.03	0.04	0.03	0.05	0.03	0.11	0.03	0.03	0.02	0.03	0.04	0.04	0.03	0.02	0.05
15	0.04	0.04	0.03	0.06	0.02	0.02	0.04	0.06	0.04	0.02	0.02	0.04	0.07	0.08	-	0.03	0.03	0.04	0.04	0.09	0.03	0.04	0.03	0.10	0.09	0.04	0.02	0.11	0.07	0.03	0.03	0.02	0.06	0.06	0.03	0.04	0.21	0.02	0.04	0.03	0.04	0.03	0.05	0.05	0.03	0.04
16	0.02	0.02	0.02	0.03	0.01	0.01	0.02	0.02	0.05	0.01	0.03	0.02	0.03	0.02	0.03	-	0.02	0.10	0.02	0.02	0.02	0.04	0.02	0.03	0.03	0.02	0.01	0.03	0.03	0.03	0.03	0.01	0.02	0.05	0.01	0.02	0.03	0.01	0.02	0.06	0.02	0.02	0.10	0.02	0.03	0.02
17	0.04	0.02	0.24	0.02	0.05	0.28	0.01	0.03	0.02	0.06	0.01	0.03	0.06	0.04	0.03	0.02	-	0.02	0.02	0.03	0.10	0.02	0.09	0.04	0.04	0.06	0.58	0.04	0.06	0.01	0.01	0.14	0.04	0.02	0.04	0.03	0.03	0.07	0.03	0.02	0.03	0.13	0.03	0.02	0.02	0.14
18	0.02	0.02	0.02	0.03	0.01	0.01	0.02	0.02	0.04	0.01	0.03	0.02	0.03	0.03	0.05	0.10	0.02	-	0.03	0.03	0.02	0.13	0.02	0.03	0.04	0.03	0.01	0.03	0.04	0.04	0.03	0.01	0.03	0.11	0.02	0.02	0.04	0.01	0.03	0.10	0.02	0.02	0.09	0.04	0.03	0.03
19	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.02	0.04	0.02	0.05	0.02	0.04	0.02	0.02	0.03	-	0.03	0.02	0.04	0.02	0.05	0.04	0.03	0.01	0.03	0.04	0.02	0.02	0.01	0.04	0.03	0.02	0.04	0.03	0.02	0.07	0.02	0.05	0.02	0.14	0.40	0.08	0.03
20	0.04	0.06	0.03	0.05	0.02	0.01	0.02	0.05	0.03	0.02	0.02	0.06	0.05	0.11	0.09	0.02	0.03	0.03	0.03	-	0.04	0.03	0.03	0.05	0.05	0.07	0.02	0.81	0.04	0.02	0.02	0.02	0.04	0.03	0.05	0.03	0.12	0.03	0.03	0.03	0.03	0.03	0.04	0.03	0.02	0.04
21	0.06	0.03	0.17	0.03	0.05	0.11	0.02	0.03	0.02	0.05	0.02	0.04	0.10	0.07	0.04	0.02	0.11	0.02	0.02	0.05	-	0.03	0.07	0.05	0.06	0.13	0.07	0.05	0.10	0.02	0.01	0.05	0.06	0.02	0.03	0.04	0.04	0.06	0.04	0.02	0.04	0.13	0.05	0.03	0.02	0.11
22	0.02	0.02	0.02	0.03	0.02	0.01	0.02	0.02	0.08	0.01	0.04	0.02	0.03	0.02	0.03	0.13	0.02	0.10	0.04	0.03	0.02	-	0.02	0.04	0.04	0.03	0.01	0.03	0.04	0.03	0.03	0.01	0.03	0.05	0.02	0.02	0.03	0.02	0.02	0.06	0.02	0.02	0.14	0.04	0.04	0.03
23	0.10	0.05	0.09	0.02	0.06	0.07	0.01	0.02	0.02	0.04	0.01	0.05	0.05	0.03	0.03	0.01	0.08	0.02	0.02	0.03	0.06	0.02	-	0.03	0.04	0.06	0.06	0.03	0.05	0.01	0.01	0.07	0.03	0.02	0.07	0.03	0.03	0.07	0.03	0.01	0.02	0.06	0.04	0.02	0.02	0.63
24	0.04	0.02	0.04	0.05	0.03	0.02	0.03	0.04	0.05	0.03	0.02	0.03	0.13	0.04	0.11	0.03	0.04	0.03	0.05	0.05	0.05	0.05	0.03	-	0.22	0.07	0.03	0.05	0.13	0.02	0.02	0.03	0.11	0.04	0.02	0.07	0.06	0.03	0.05	0.03	0.06	0.04	0.09	0.07	0.03	0.05
25	0.04	0.02	0.04	0.04	0.03	0.03	0.02	0.03	0.04	0.02	0.02	0.03	0.12	0.04	0.07	0.02	0.04	0.03	0.03	0.04	0.05	0.04	0.03	0.18	-	0.06	0.03	0.04	0.24	0.02	0.01	0.03	0.25	0.03	0.02	0.11	0.05	0.03	0.06	0.02	0.08	0.03	0.07	0.05	0.03	0.05
26	0.10	0.05	0.07	0.04	0.04	0.05	0.02	0.05	0.03	0.03	0.02	0.05	0.12	0.06	0.04	0.02	0.06	0.02	0.02	0.07	0.11	0.03	0.06	0.06	0.08	-	0.04	0.08	0.12	0.01	0.01	0.04	0.07	0.03	0.04	0.05	0.07	0.04	0.04	0.02	0.04	0.06	0.05	0.03	0.02	0.07
27	0.04	0.02	0.18	0.02	0.05	0.19	0.01	0.03	0.02	0.05	0.01	0.03	0.06	0.04	0.03	0.02	0.75	0.02	0.02	0.03	0.08	0.02	0.08	0.03	0.04	0.06	-	0.03	0.06	0.01	0.01	0.18	0.04	0.02	0.03	0.03	0.03	0.06	0.03	0.02	0.03	0.11	0.04	0.02	0.02	0.13
28	0.04	0.06	0.03	0.06	0.02	0.02	0.03	0.12	0.03	0.02	0.02	0.06	0.05	0.11	0.05	0.02	0.03	0.03	0.03	0.78	0.04	0.03	0.03	0.05	0.05	0.08	0.02	-	0.04	0.02	0.02	0.02	0.03	0.04	0.05	0.03	0.14	0.02	0.03	0.03	0.02	0.03	0.05	0.03	0.02	0.04

O/D	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46
29	0.05	0.03	0.05	0.03	0.03	0.04	0.02	0.03	0.03	0.03	0.02	0.03	0.21	0.05	0.05	0.02	0.05	0.03	0.03	0.03	0.07	0.03	0.04	0.10	0.22	0.10	0.03	0.04	-	0.01	0.01	0.03	0.31	0.02	0.02	0.12	0.04	0.03	0.06	0.02	0.09	0.04	0.06	0.04	0.03	0.05
30	0.02	0.02	0.01	0.02	0.01	0.01	0.02	0.02	0.03	0.01	0.02	0.02	0.03	0.03	0.04	0.03	0.02	0.04	0.02	0.02	0.02	0.04	0.01	0.02	0.02	0.02	0.01	0.03	0.02	-	0.09	0.01	0.02	0.04	0.02	0.02	0.03	0.02	0.02	0.09	0.02	0.02	0.06	0.03	0.02	0.02
31	0.02	0.02	0.01	0.02	0.01	0.01	0.02	0.02	0.03	0.01	0.02	0.02	0.02	0.02	0.04	0.03	0.02	0.04	0.02	0.02	0.01	0.04	0.01	0.02	0.02	0.02	0.01	0.03	0.02	0.09	-	0.01	0.02	0.04	0.01	0.02	0.03	0.01	0.02	0.07	0.02	0.01	0.42	0.02	0.02	0.02
32	0.04	0.02	0.08	0.02	0.05	0.08	0.01	0.02	0.02	0.06	0.01	0.02	0.05	0.03	0.03	0.01	0.17	0.02	0.02	0.03	0.06	0.02	0.08	0.03	0.04	0.05	0.17	0.02	0.05	0.01	0.01	-	0.03	0.02	0.04	0.03	0.03	0.06	0.03	0.01	0.02	0.06	0.04	0.02	0.02	0.06
33	0.04	0.03	0.05	0.03	0.03	0.03	0.02	0.03	0.03	0.02	0.02	0.03	0.09	0.04	0.06	0.02	0.04	0.02	0.04	0.04	0.05	0.03	0.03	0.10	0.29	0.07	0.03	0.03	0.40	0.02	0.02	0.03	-	0.03	0.03	0.19	0.04	0.03	0.07	0.02	0.12	0.04	0.05	0.04	0.03	0.05
34	0.02	0.02	0.02	0.05	0.02	0.02	0.03	0.03	0.10	0.02	0.02	0.02	0.04	0.04	0.07	0.05	0.02	0.12	0.04	0.04	0.02	0.08	0.02	0.04	0.04	0.03	0.01	0.05	0.04	0.04	0.04	0.02	0.03	-	0.02	0.03	0.05	0.02	0.03	0.05	0.02	0.02	0.12	0.05	0.04	0.03
35	0.05	0.11	0.04	0.03	0.03	0.03	0.01	0.04	0.02	0.03	0.01	0.05	0.04	0.05	0.04	0.01	0.04	0.02	0.02	0.05	0.03	0.02	0.08	0.02	0.03	0.04	0.03	0.06	0.03	0.02	0.01	0.04	0.03	0.02	-	0.02	0.04	0.04	0.02	0.02	0.02	0.01	0.08	0.02	0.02	0.10
36	0.03	0.02	0.04	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.07	0.03	0.05	0.02	0.03	0.02	0.04	0.03	0.04	0.03	0.03	0.07	0.14	0.05	0.02	0.03	0.16	0.02	0.02	0.02	0.21	0.02	0.02	-	0.03	0.03	0.09	0.02	0.33	0.03	0.05	0.06	0.03	0.04
37	0.03	0.04	0.04	0.10	0.02	0.02	0.04	0.07	0.03	0.02	0.02	0.05	0.06	0.12	0.25	0.03	0.03	0.04	0.03	0.14	0.04	0.04	0.04	0.07	0.06	0.08	0.03	0.17	0.06	0.03	0.02	0.02	0.05	0.05	0.04	0.04	-	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.03	0.04
38	0.04	0.03	0.07	0.02	0.11	0.05	0.01	0.04	0.02	0.12	0.01	0.03	0.04	0.03	0.02	0.01	0.06	0.01	0.02	0.03	0.05	0.02	0.07	0.03	0.03	0.04	0.05	0.02	0.04	0.01	0.01	0.05	0.03	0.02	0.03	0.02	0.02	-	0.03	0.01	0.02	0.05	0.03	0.02	0.02	0.12
39	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.04	0.02	0.03	0.01	0.02	0.02	0.05	0.02	0.02	0.02	0.02	0.03	0.05	0.03	0.01	0.02	0.06	0.01	0.01	0.02	0.05	0.02	0.01	0.06	0.02	0.02	-	0.02	0.08	0.02	0.07	0.06	0.03	0.03
40	0.02	0.02	0.01	0.02	0.01	0.01	0.02	0.02	0.02	0.01	0.02	0.02	0.03	0.02	0.03	0.05	0.02	0.08	0.02	0.03	0.01	0.07	0.01	0.02	0.03	0.02	0.01	0.03	0.03	0.08	0.06	0.01	0.02	0.04	0.02	0.02	0.03	0.01	0.02	-	0.02	0.03	0.07	0.02	0.03	0.02
41	0.03	0.02	0.03	0.02	0.02	0.02	0.01	0.02	0.03	0.02	0.02	0.02	0.06	0.03	0.04	0.02	0.03	0.02	0.05	0.03	0.04	0.03	0.03	0.06	0.03	0.05	0.02	0.03	0.12	0.02	0.02	0.02	0.13	0.02	0.02	0.33	0.03	0.02	0.12	0.02	-	0.03	0.07	0.06	0.03	0.04
42	0.04	0.03	0.26	0.02	0.05	0.16	0.01	0.03	0.02	0.07	0.01	0.03	0.07	0.05	0.03	0.02	0.15	0.02	0.02	0.04	0.14	0.02	0.08	0.04	0.05	0.08	0.08	0.04	0.07	0.02	0.01	0.06	0.04	0.02	0.01	0.04	0.03	0.06	0.03	0.03	0.03	-	0.05	0.03	0.02	0.13
43	0.02	0.02	0.02	0.02	0.01	0.02	0.01	0.02	0.10	0.01	0.08	0.02	0.04	0.02	0.02	0.04	0.02	0.04	0.06	0.02	0.02	0.08	0.02	0.04	0.04	0.03	0.01	0.03	0.04	0.02	0.16	0.01	0.02	0.05	0.03	0.02	0.02	0.01	0.04	0.03	0.03	0.02	-	0.08	0.12	0.03
44	0.02	0.01	0.02	0.03	0.02	0.02	0.02	0.02	0.05	0.02	0.04	0.02	0.05	0.02	0.05	0.02	0.02	0.03	0.35	0.03	0.03	0.05	0.02	0.06	0.06	0.03	0.02	0.03	0.05	0.02	0.02	0.02	0.04	0.04	0.02	0.05	0.03	0.02	0.07	0.02	0.05	0.02	0.16	-	0.07	0.03
45	0.02	0.01	0.02	0.02	0.01	0.01	0.01	0.02	0.05	0.01	0.03	0.01	0.03	0.02	0.03	0.03	0.02	0.03	0.07	0.02	0.02	0.05	0.02	0.03	0.03	0.02	0.01	0.02	0.03	0.02	0.02	0.01	0.03	0.03	0.01	0.03	0.02	0.02	0.04	0.03	0.03	0.02	0.26	0.07	-	0.02
46	0.08	0.04	0.07	0.02	0.07	0.09	0.01	0.02	0.02	0.07	0.01	0.05	0.05	0.03	0.03	0.01	0.10	0.02	0.02	0.02	0.07	0.02	0.45	0.03	0.04	0.05	0.07	0.03	0.05	0.01	0.01	0.08	0.04	0.02	0.06	0.03	0.03	0.08	0.03	0.01	0.03	0.07	0.04	0.02	0.02	-

List of papers published

1. Anil M, Prasad CSRK (2016) Planning and Evaluation of Rural Road Network Connectivity Using GIS. *Geo-china 2016*, pp. 83-90, DOI: 10.1061/9780784480106.011 (Publisher: ASCE)
2. Anil M, Prasad CSRK, Chandra M (2016) Facility Based Planning Methodology for Rural Roads Using Spatial Techniques. *Journal of Innovation Infrastructure Solutions*, Volume 1, Issue 1, DOI 10.1007/s41062-016-0041-8 (Publisher: Springer Nature)
3. Anil M, Prasad CSRK Design Optimal Rural Road Network Using GIS (2017). *Archives of Transport*, Volume 41, Issue 1, pp. 63-71 (Publisher: Polish Academy of Sciences)