APPLICATIONS OF GEOGRAPHIC INFORMATION SYSTEMS IN PLANNING FOR PEDESTRIAN TRAIL BRIDGES IN NEPAL

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

Rural accessibility is a pressing issue in many parts of the world. Improved geographical accessibility to basic social service facilities for rural populations is a goal of most governments in developing countries. Development of a trail-based transport system is a key way to improve rural accessibility in mountainous and rugged terrain where trails criss-cross with numerous rivers. The present study focuses on Nepal, a developing country with rural accessibility challenges and a very challenging physical environment. This thesis reviews the existing accessibility patterns in rural areas of Nepal and proposes various approaches for identifying poorly served geographical areas and optimizing of location of additional new trail bridges to provide "best" links to social services. The methodology in this study is based on the concept of the gravity-based spatial interaction and accessibility models. GIS applications are used in different ways, such as in creating, acquiring, integrating spatial and attribute datasets, and spatial analysis and visualization of the output results. Amongst the different types of social services, health care and education centers are considered the most pressing services and hence are the objects of analysis. The main difference between health care service centers and educational facilities is that schools are usually very widespread across the district and serve for the school age population. Health service centers are sparsely and inequitably distributed, however, they serve the whole population at large. The results of the analysis show a fairly clear indication of problems relating to rural transport and access to social service centers in rural Nepal. This is attributed, in part, due to insufficient provision of social service centers and the lack of trail bridges over river crossing locations. The estimated numbers of trips over potential new bridges based on spatial integration modeling provides a basis for prioritization of river crossing locations for allocation of new trail bridges. The poorly served areas across the study district are identified on the basis of the results of the potential accessibility modeling. The trail network nodes with relatively low accessibility values are of prime concern and the subject of contemplation in the trail bridge planning decision-making process.

Acknowledgements

The completion of this thesis would not have been possible without generous assistance and input from many remarkable people.

I would like to extend my gratitude to my supervisors Dr. Jean Andrey and Dr. Douglas Dudycha for their invaluable guidance, many thoughtful insights and constructive comments throughout the development of this thesis. Their insights led to this research becoming a considerably more meaningful and comprehensive contribution to the literature in understanding the spatial interaction of rural communities with the essential social services.

I would like to thank Scott MacFarlane who took time out of his busy schedules to assist me in my research. A special thanks for my friends in the transportation geography group for their views and insights in transport related contemporary issues in a weekly regular discussion meeting setting. Your encouragement is greatly appreciated.

Finally, I would like to thank my family for their patience, inspiration and continuing support.

Dedication

This thesis is dedicated to my wife Sirjana,
daughter Anagha and
son Abhigya.

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List of Acronyms

CIDA	Canadian International Development Agency
DDC	District Development Committee (District level local government body in Nepal)
DFID	British Department for International Development (United Kingdom)
ESRI	Environmental Systems Research Institute
GIS	Geographic Information Systems
Helvetas	Swiss Association for International Cooperation (Switzerland)
ICIMOD	International Centre for Integrated Mountain Development (Nepal)
IRAP	Integrated Rural Accessibility Planning
MENRIS	Mountain Environment and Natural Resources Information System (Nepal)
RTI	Rural Transport Infrastructure
SDC	Swiss Agency for Development and Cooperation (Switzerland)
TIM	Transport Infrastructure Map (Nepal)
UNDP	United Nations Development Program
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
VDC	Village Development Committee (Village level local government body in Nepal)
WGS	World Geodetic Survey

Chapter 1
INTRODUCTION

1.1 Rural Accessibility and Transportation Issues in Developing Countries

1.1.1 Rural Accessibility

Rural accessibility is a pressing issue in many parts of the world. Improved geographical accessibility to basic social services (health centers, schools, local markets, post offices, etc.) for rural populations is a goal of most governments in developing countries. Rural people in developing countries face several accessibility restrictions when trying to fulfill their needs (Vasconsellos, 1997). Almost 50 percent of the world's population lives in rural areas, and over 65 percent of the population in developing countries is rural (United Nations, 2005). Rural transport networks in most developing countries are underdeveloped and of poor quality (Nutley, 1998).

Rural communities spend much time and effort on transport activities to fulfill their basic needs. It is estimated that about 900 million rural people in developing countries do not have reliable all-season access to main road networks, and about 300 million people do not have motorized access at all (Lebo and Schelling, 2001). Their lives are characterized by isolation, exclusion, and unreliable access to even the most basic economic opportunities and social services. For the majority of their transport needs, they rely on non-motorized means and on rugged paths, tracks, foot trails and roads which are typically in poor condition and often only passable in dry weather (Appendix A). At the same time, resources are being spent on upgrading roads to higher than economically justified standards for populations that already have a reasonable level of access (Lebo and Schelling, 2001).

Rural poverty in developing countries is attributable, in part, to the absence of road access over larger areas (Hoyle et al., 1998). Poverty and accessibility are correlated to a certain extent and also poverty and ill-health prevalent among rural population in developing countries is compounded by poor physical access (Porter, 2002). The lack of affordable access to adequate infrastructure is a key factor determining the nature and persistence of poverty (Kessides, 1993). Chambers (1980) and

Howe (1997) have stressed the coincidence of poverty, physical isolation and immobility in the rural context. There is clear evidence that poverty is more persistent in areas with no or unreliable motorized access as compared to more accessible areas. Lebo and Schelling (2001) comment, for example, that in Nepal, where the percentage of people below the poverty line is approximately 42 percent, the incidence of poverty in unconnected areas is as high as 70 percent. In Bhutan, the enrollment of girls in primary schools is three times as high in connected villages compared to unconnected ones. Likewise, in India, the female literacy rate is 60 percent higher in villages with all-season road access compared to those with unreliable access.

Rural transport development requires a broad understanding of the mobility and access needs of rural communities (Lebo and Schelling, 2001). From a rural development perspective, it can be argued that the affected communities themselves should lead demand-driven participatory approach of accessibility planning (Lebo and Schelling, 2001). Rural transport consists of three elements: (a) location and quality of facilities, (b) transport infrastructure, and (c) transport services. Access problems can be solved only when all three elements of rural transport are available. For effective utilization and allocation of available resources, country-specific rural transport policies and strategies are required (Lebo and Schelling, 2001).

Provision of some level of access is often viewed as a basic human right similar to the provision of basic health services and basic education (Lebo and Schelling, 2001). Providing basic access to markets for local products and social services for the people who live in rural areas is one of the most significant challenges in developing countries. The basic-needs strategy aims at meeting the requirements of the poor for minimum access to essential social services (Blaikie et al., 1979). Consistent with a basic-needs focus, the basic-access approach gives priority to the provision of reliable, all-season access, to as much population as possible (Lebo and Schelling, 2001; Beenhakker et al., 1987; Blaikie et al., 1979). Lack of reasonably reliable and economic means of personal and goods transport in rural areas is thought to be major constraint to rural development (Beenhakker et al., 1987). “Getting to market to sell produce, getting to school, and obtaining medical services … can be difficult tasks for the rural communities in general, but for the people of off-road settlements the hurdles to be crossed are additionally complex” (Porter, 2002: 288). Hence, transport infrastructure and transport means play a vital role in attaining the basic needs of rural population (Barwell et al, 1985 as cited in Vasconcellos, 1997).

In developing countries, the provision of basic access is limited by the availability of resources. Affordability, therefore, will primarily be determined by a population's capacity to maintain its basic access infrastructure over the long term (Lebo and Schelling, 2001). In cases where motorized access is not affordable, improvements to the existing trail networks and the provision of trail bridges over river crossing locations would be the only affordable and also reliable alternative. The rural people have long utilized traditional transport modes such as head baskets, carts and pack animals to assist in their transport activities and fulfill their transport needs (Beenhakker et al., 1987).

Transport is clearly a necessary element of nearly every aspect of human activities and economic and social development. Personal mobility and the transport of goods are part and parcel of everyday life. The quantity and quality of transport infrastructure in a region is a key determinant, in part, for people's well-being in that region (Kanbur and Venables, 2005). The utility of transport programs primarily rests in their contributions to improved accessibility and reduction of related costs (Howe and Richards, 1984). Most developing countries have made considerable progress in providing a basic network of primary and secondary traffic arteries, basically major highways, connecting major administrative and economic centers (Beenhakker et al., 1987). However, there is an insufficient network of rural transport infrastructure that connects rural areas to a country's main road networks (Barwell, 1996). This situation needs to be addressed to improve rural accessibility.

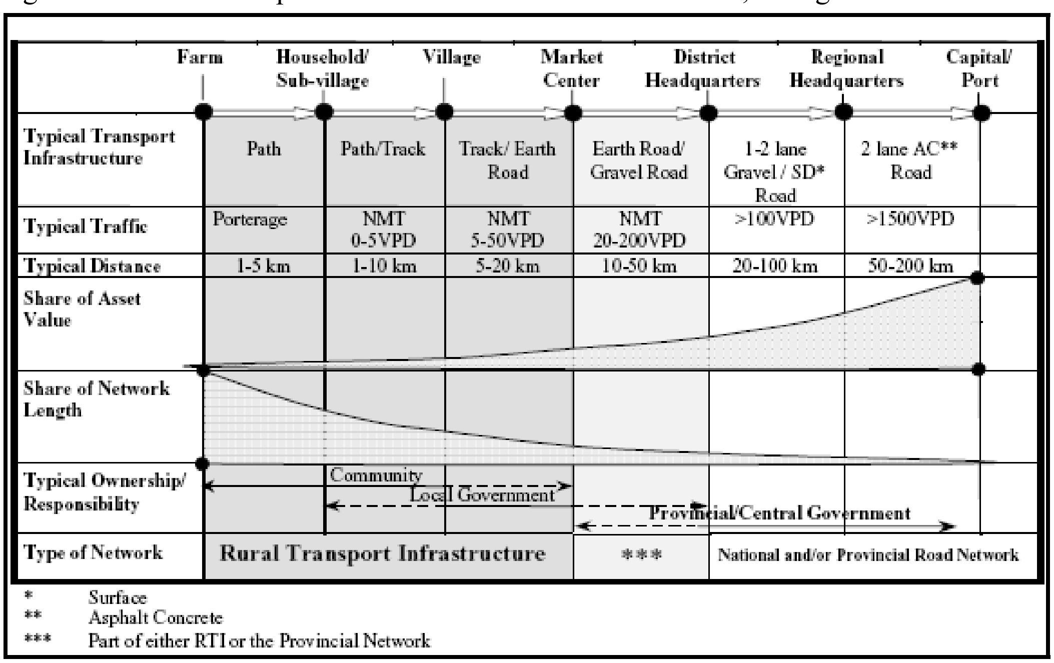
Pedestrian trails are essential elements of rural accessibility in many developing countries especially in regions with rugged terrain. The nature and extent of trail conditions vary across the regions of the world. Most often, in hilly and mountainous terrains, trails are generally steep, slippery and have narrow path (Barwell, 1996). These trails also lack reliable river crossing facilities, especially trail bridges.

Rural transport infrastructure (RTI) comprises the rural road, track, bridges and pedestrian trail network on which the rural population performs its transport activities, which includes walking, transport by non-motorized and motorized vehicles, and haulage and transport of people by animals

(Lebo and Schelling, 2001). RTI includes the intra- and near-village transport network, as well as the infrastructure that provides access to higher levels of the road network (Lebo and Schelling, 2001). The RTI network is the lowest level of transport system that connects the rural population to their farms, local markets, and social services such as schools and health care service centers in a close proximity to the settlement villages. A minimum level of service of the RTI network is, therefore, one of the basis access needs of the rural population.

The RTI network in developing countries consists of an estimated 5-6 million kilometers of rural roads, tracks and paths and pedestrian trails (Lebo and Schelling, 2001). The majority of trips that take place over RTI constitute short distances (less than five kilometers) and are made by non-motorized means, including walking, animals, bicycle, and porterage (Barwell, 1996 as cited in Lebo and Schelling, 2001). Given the considerable degree of dependence on travel by foot, carrying loads on the heads or the back, it is the distance to facilities that is the prime determinant of trip time and effort spent on transport, and frequency of utilization of the services offered (Barwell, 1996). The utilization of social facilities, such as health centers, schools, and markets relates to the level of physical access, i.e., distance travelled and availability of means of transport (Barwell, 1996). Figure 1-1 depicts the key features of rural transport infrastructure.

Figure 1-1: Rural Transport Infrastructure and Access to Farms, Villages and Market Centers



Source: Lebo and Schelling, 2001: 9.

Worldwide experience from past rural development programs and policies suggests that improving the poverty impact of RTI interventions requires an emphasis on reliable, cost-effective access to as much of the rural population as possible, rather than high access standards for a few (World Bank, 2001). As much of the rural travel is on foot, improvements to footpaths, tracks and foot bridges (trail bridges) can have a significant impact on the efficiency of rural travel and transport (Barwell, 1996). Improvements can be made substantially by increasing the safety of river crossings so that people do not have to make long detours to avoid dangerous river crossings (Barwell, 1996).

Consistent with this premise, this study focuses on Nepal, a developing country with serious rural accessibility challenges and a very challenging physical environment. This thesis reviews the existing accessibility patterns in rural areas of Nepal and proposes and tests various approaches for optimizing the location of future trail bridges to provide “best” links to social services to improve rural accessibility in Nepal (Section 1.3, Section 3.1.1).

1.1.2 Accessibility to Social Service Centers in Rural Areas

1.1.2.1 Transport Services

Transport is a part of the daily rhythm of life. The purpose of transport is to provide accessibility, or the ability to make a journey for a specific purpose (Hoyle et al., 1998). Many developing countries have been struggling to find the resources to provide a basic level of access, especially in rural areas. It is normally assumed that access to a basic minimum range of facilities is economically and socially necessary for the pursuit of a normal way of life (Hoyle et al., 1998). The rural problem, therefore, is the lack of accessibility (Hoyle et al., 1998). Accessibility decisions are critically important to development “because a large proportion of the population in developing countries is rural and their transport and communication systems are poorly developed and costly to use” (Rusthon, 1984: 217). Essential social services are harder to reach from rural areas than in towns and cities (Haynes et al., 2003). Rural people might be doubly disadvantaged because they live far from the service centers and do not have access to reliable transport infrastructure and services (Haynes et al., 2003). A country’s ability to maximize its economic potential is closely linked to the efficiency of its transport system.

Transport improvements also help to reduce poverty through improving the quality and security of access to employment, markets and social services (Gannon et al., 2001).

Almost half of the world's population lives in rural areas where lack of proper transport is a constraint for development and such condition will continue for many decades to come (Ravallion, 2000; United Nations, 2005). The predominant means of transport in the rural areas of developing countries is walking (Barwell et al., 1985). Barwell et al. (1985) and Gannon et al. (2000) comment that people make their journeys with loads carried on their head (India, Sub-Saharan Africa), on the back (Korea, Nepal, Sub-Saharan Africa) and shoulder (Malaysia, Nepal) (Figure 1-2). People are used to waking days, sometimes weeks carrying essential things to help them in their day-to-day survival.

Social services constitute an integral part of the infrastructure required for development in rural areas. The spatial distribution of social services depends basically on the location of human settlements in an area and, more importantly on the level of accessibility. Social service delivery in rural areas is more effective if there is trouble-free accessibility. Properly located services complemented by bridged river crossings that provide uninterrupted access can enable government to provide the best possible services to the communities (MENRIS, 1994).

Figure 1-2: Different modes of load transport on a trail

Photo source: Trail Bridge Section, Nepal.

Photo source: Barwell, 1996.

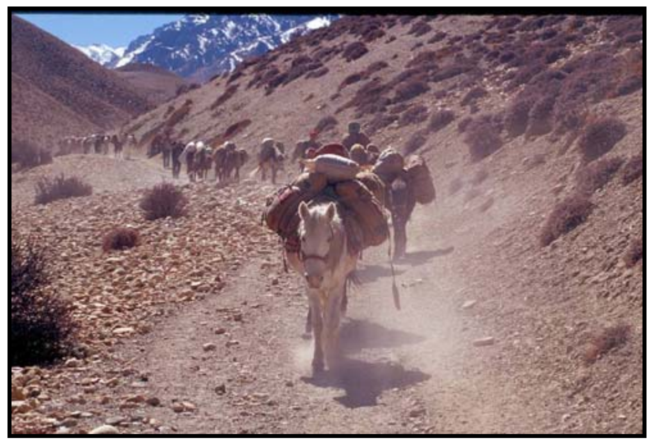


Photo source: http://www.awstevenson.com/

1.1.2.2 Accessibility to Social Service Centers

Accessibility is a fundamental topic of transport geography. The history of accessibility is typically expressed as the history of the development of particular measures, such as topological, cumulative opportunity, population potential or space-time (Kwan and Weber, 2003; Horner, 2004 as cited in Weber, 2006). Weber (2006) argues that the geographical concept of accessibility is based on the following: there must be some spatial separation of origins and destinations, such as between population settlements and service centers, which people have a need or desire to move between. There must also be an impedance or restriction on movement which can be travel distance, travel time or cost of travel.

The concept of accessibility is used in many contexts and in many different ways; for instance as a goal in transportation policy, as a means in rural development policy, as an indicator of rural deprivation, and as a variable in location analysis (Moseley, 1979). Accessibility can be defined as the ease or difficulty of reaching or using a facility or service, and therefore, concerns both the mobility of people and the availability of services (IRAP, 2005; Barwell et al., 1996). Accessibility can also measure the relative opportunity for interaction or contact with facilities or services (Nicholls, 2001). Barwell et al. (1996) from their studies (Edmonds and Barwell, 1993) note that the level of physical accessibility is dependent on two factors: a) the level of mobility; and b) the siting and quality of facilities. Odoki et al. (2001) define accessibility as a function of the mobility of the individual and the spatial location of activity opportunities. The siting and quality of facilities affects the distances and routes between the places of residence or production and the facilities that people make a decision to use (Barwell et al., 1996).

Accessibility of people in general can be improved either by enhancing mobility through the development and provision of transport infrastructure and services or by locating facilities and services closer to rural communities (Barwell, 1996). Locating facilities close to settlements and improved management of accessibility to these services are the key elements of location allocation and resource management (IRAP, 2005).

The definition of accessibility can be based on the theories of travel behavior. The amount and nature of movement of people derives from the amount and nature of activities (Mitchell and Rapkin, 1954 as cited in Handy and Niemeier, 1997). Measures of accessibility consist of two parts: a transportation element (resistance or impedance) and an activity (motivation or attraction) element (Burns, 1979; Koenig, 1980 as cited in Handy and Niemeier, 1997). The transportation element reflects the ease of travel between the origin and destination points determined by the character and quality of service provided by the transportation system and measured by travel distance, time or cost involved for the activity (Burns, 1979; Koenig, 1980 as cited in Handy and Niemeier, 1997). The activity element reflects the spatial distribution of activities or attractiveness of a particular location or trip destination (Handy and Niemeier, 1997).

Handy and Niemeier (1997) define accessibility as spatial distribution of potential destinations, the ease of reaching each destination, and the magnitude, quality and character of the activities available there. The parameters of accessibility as the ‘rural challenge’ were set out by Moseley (1979) who viewed accessibility as the degree to which someone or something is ‘get-at-able’. Farrington et al. (2005) define accessibility to be the ability of people to reach and engage in opportunities and activities related to mobility and transport use. Reach implies spatial separation and therefore is related to mobility and transport use. Viewed as opportunities, accessibility is concerned with the opportunities that an individual or community at a given location possesses to take part in a particular activity or set of activities (Jones, 1981). Bryceson et al. (2003) define accessibility as physical proximity or the ability and ease of reaching various destinations or places offering opportunities for a desired activity. Hansen (1959) characterizes accessibility as the potential for interaction.

In planning, accessibility has been used for locating facilities such as schools, health care service centers, administrative service centers, recreation and religious centers, and transport infrastructure and services. Accessibility to economic, recreational, service and social opportunities within a region is an important component of the quality of life within the region (Wachs and Kumagai, 1972). It is also considered an element of the quality of life which influences public policies related to the development of public transportation and communication systems, and location of economic and public services (Wachs and Kumagai, 1972). More importantly, the provision of some form of access is vital for the mobility of people and goods and, in turn, for the development of the economy (Barwell et al., 1985).

Levels of accessibility vary by density of population, patterns of settlements and service provision, and level of income among other things. In addition, the levels of accessibility to social services vary between societies and also depend on the geographic location of the settlements, topography of the landscape and availability of transport services (Farrington et al., 2005). Accessibility is determined both by the patterns of land use planning and by the nature of transportation facilities (Handy and Niemeier, 1997).

The transport situation especially in rural areas, generally, can be characterized as (Gannon et al., 2001; Barwell et al., 1985):

a) Rural communities are isolated for extended periods as they lack reliable all-season road access. Operations of motorized vehicles are rare and often limited to government agencies and also to non-governmental development agencies.

b) Most trips are short, frequent, time- and effort consuming, and linked to subsistence needs such as collecting water and fuel, crop production, harvesting and processing, etc.

c) Less frequent and longer distance trips are made for visiting hospitals or health service centers, marketing produce, social purposes, etc. Trips for social and welfare activities are a significant proportion of the longer trips made outside the communities. The siting of essential social services thus influences the nature of rural transport requirements.

d) Rural people do not own and rarely can secure access to motorized transport services. They are reliant on walking, and non-motorized transport especially head, shoulder and back loading, and predominantly animals (mules, cattle, horses, etc.) for carrying loads (Figure 1-2).

In order to address the transport needs of the rural population, it has to be considered that the pedestrian trails and tracks and methods of movements on these trails and tracks are the essentials elements of the rural transport system and also, equally worthy of attention as engineered roads and motor vehicles (Barwell et al., 1985). The provision of rural transport services needs to be viewed in terms of overcoming the constraints and alleviating the problems faced by the rural communities. Planning of rural transport improvements should be based on the analysis of specific local-level mobility needs at the community level. Analysis of the range of transport needs should lead to identification of the most effective way of utilizing scarce resources to overcome critical transport constraints. An important consideration would be the appropriate distribution of social services and access to these services which can significantly influence the short- and long-distance transport requirements of communities (Barwell et al., 1985). Accessibility to services can be measured by reference to the origin and destination locations taking into account the travel modes. People in more remote areas often have lower levels of accessibility, even though their needs might be as great as people in less remote areas who experience relatively higher level of accessibility (Farrington et al., 2005).

‘‘Historically, nobody has been responsible for ensuring that people can get to key services and employment sites. As a result, services have developed with insufficient attention to accessibility. In addition, too often access to services has been seen as merely a transport issue rather than one that can be solved by, for example, better land-use planning, or through policies …’’ (Social Exclusion Unit, 2003:40 as cited in Farrington et al., 2005).

1.2 Transport Sector and Accessibility to Social Services in Nepal

1.2.1 Transport and Accessibility

The World Bank (2001) emphasizes that in order to complement poverty reduction strategies, development of rural transport infrastructure and services must be an integral part of rural development interventions and should focus on the mobility and basic access needs of rural communities. As the majority of the population lives in the rural areas and is lacking road transport access, providing road access and uninterrupted linkage to economic and social service centers by constructing roads and bridges is considered a development priority program in Nepal. Personal mobility has been considerably stimulated by the availability of public transport services, particularly as an alternative to the porterage of head loads (Howe and Richards, 1984). Few regular transport services operate away from all-weather road networks. However, many people live remote from such networks and hence lack access to motorized transport services. Also, the lack of safe, reliable and durable means of river crossings, especially trail bridges, along the pedestrian trails has been acknowledged as a key constraint to improving the living conditions of people in the rural areas (Trail Bridge Section, Nepal, 2005).

Until the late 1950’s, pedestrian foot-trails and mule tracks were the only means of transport and communication throughout the country. Since then, considerable efforts have been made to link important geographical areas and socio-economic services of the country with transport services. At present (2006), a network of approximately 21,000 km of roads has been realized (Department of Roads, Nepal, 2006). Most of these roads are concentrated in the southern part (plain terrain) of the country and in some mid-hill districts (Figure 1-3). The pace of expansion of the road network and subsequently road bridges to the rural areas is fairly slow as compared to the accessibility needs of the people. There is unlikely to be a significant improvement in this situation for the foreseeable future given the limited resources and capacity available for the expansion of road networks and transport services. Hence, trail and trail bridges provide and will continue to provide, in the foreseeable future, major transportation linkages in rural areas. The socio-economic activities of these places will continue to largely depend on a trail-based transport and communication systems made up of foot trails and mule tracks with reliable trail bridges.

For isolated communities and settlement villages in the hills of Nepal, safe and durable trail bridges are still an acute need for improving accessibility. Providing basic access needs for the rural people is still a challenging task. Considering the circumstances and the significance of trail bridges in rural development efforts, the Government of Nepal has adopted a trail bridge program as a top development priority program (National Planning Commission, Nepal, 2005). Roads, bridges, pedestrian trails and trail bridges complement each other in their operations and serve various transport needs of rural communities (Figure 1-4). All these components of the transport system need to be considered as integral components of a transport system.

Figure 1-3: Road transport - difficult and unreliable; frequent road blocks and disruption of traffic movement are fairly common due to landslides and debris flow and in some instances lack of bridges over river crossing locations.

Photo source: Trail Bridge Section, Nepal, 2005.

Photo source: B. Devkota

Figure 1-4: A typical situation of interaction of a village at one side of the river with a road and market center at the other side through a trail bridge

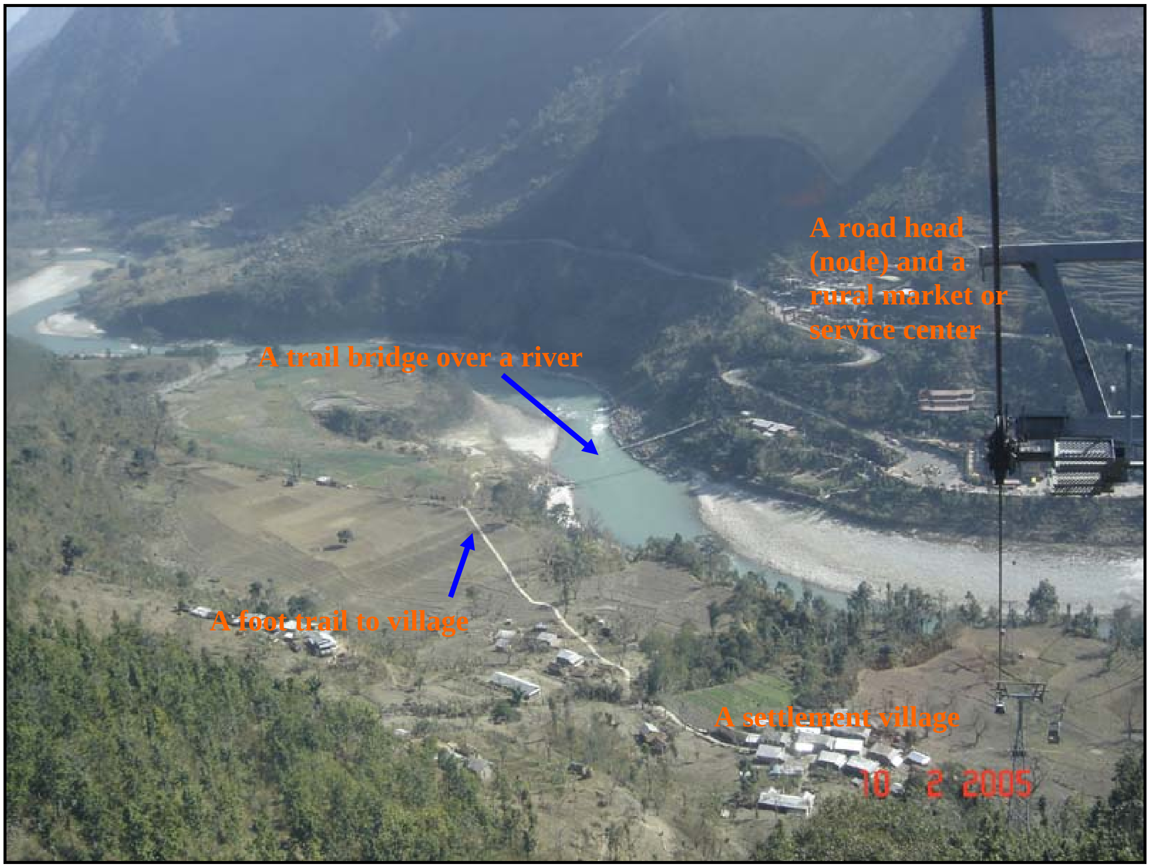


Photo source: B. Devkota

1.2.2 Rural Accessibility and Trail Bridges in Nepal

Planned intervention in development by the Government of Nepal started in the 1950's with the formulation of five-year development plans (Trail Bridge Section, Nepal, 2001). The development plans are largely guided by the principle of decentralization as well as the involvement of the private sector and civil society in carrying out development activities. In 1999, the decentralization process was reinforced through the adoption of the Local Self Governance Act shifting the responsibility for development activities from the central government departments to the district, municipal and village level government bodies. Among other development activities, the District Development Committees have the responsibility to supervise and administer the development of trail bridge programs in cooperation with the respective Municipalities and Village Development Committees.

Trail bridge building has a long history and strong tradition (Section 3.1.4) in the hills and mountains of Nepal. The annual pace of construction of trail bridges in the beginning of the 20^{th} century was very slow and only a few trail bridges were constructed at some important (especially at some trade routes) river crossing locations. Only in around 1980's the annual number of trail bridges being constructed across the country went up substantially considering their significance in rural accessibility improvement. In recent years approximately 250 to 300 trail bridges are being constructed or rehabilitated, annually. A summary of trail bridge construction progress over the years 1908-2004 is illustrated in Figure 1-5 and Figure 1-6.

Figure 1-5: Trail bridge construction cumulative progress in Nepal over the years: 1908-2004

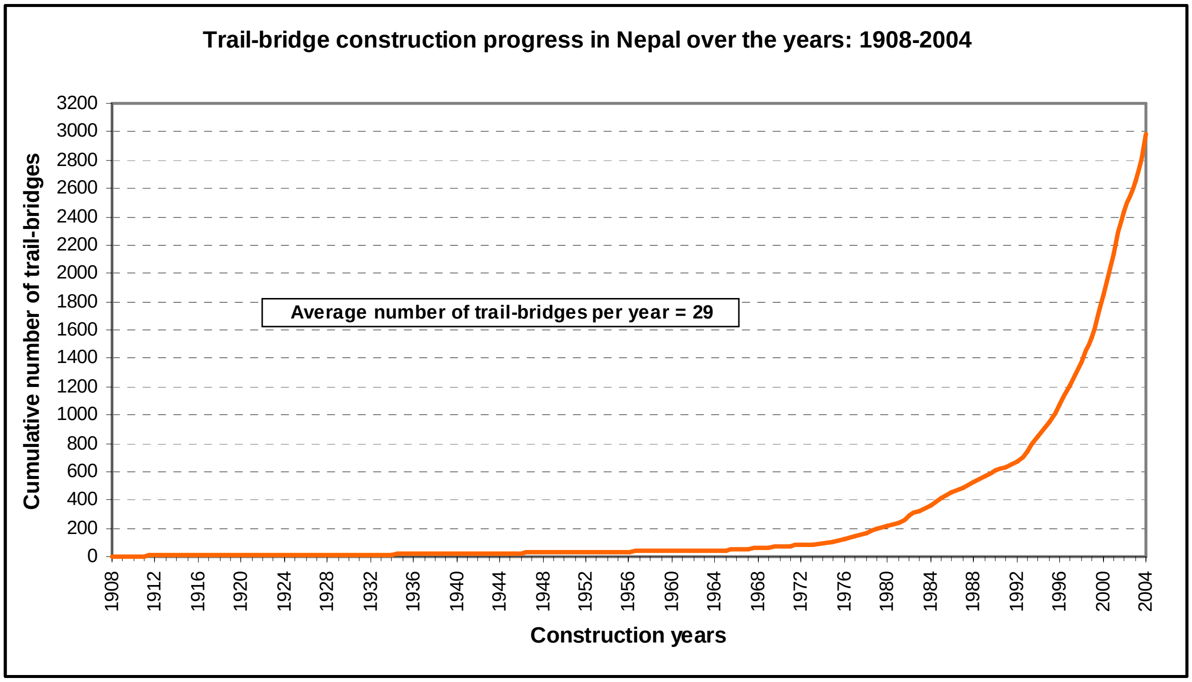
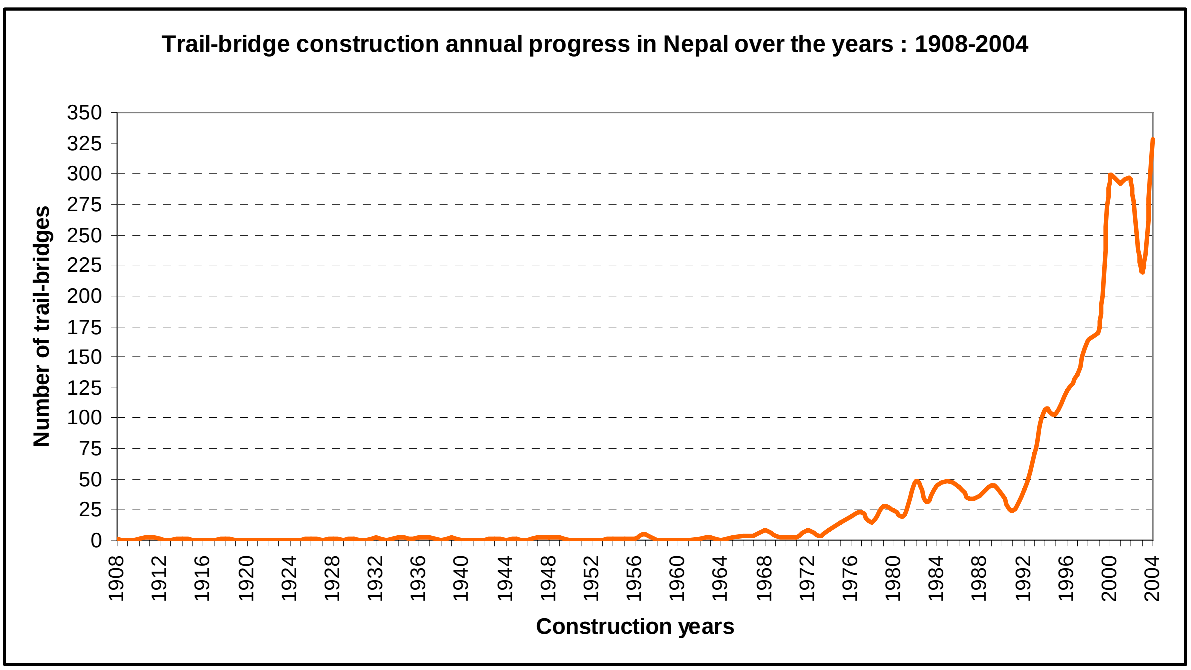


Figure 1-6: Trail bridge construction annual progress in Nepal over the years: 1908-2004



Data source for Figure 1-5 and Figure 1-6 : Nepal Trail Bridge Record, Trail Bridge Section, Nepal, 2005.

In view of the current trend of trail bridge construction practices, a tentative annual allotment of trail bridges can be estimated. It is estimated that the total current need of trail bridges across the country is approximately 6,000 (Trail Bridge Section, Nepal, 2005). The total number of trail bridges constructed so far (2004) is approximately 3,000. The new requirement will be the remaining 3,000 new trail bridges and replacement or rehabilitation of the existing old bridges constructed in the past years. Based on past experience, the replacement or rehabilitation will be at an estimated rate of 2 percent of the total bridges constructed in the past years. It can be assumed that the rate of replacement or rehabilitation will more or less remain the same, as the bridges constructed after 1990's last longer as they are comparatively new and also have better quality construction materials. With these circumstances each district will be allocated approximately 4 to 5 additional new trail bridges annually (Trail Bridge Section, Nepal, 2005). The allocation is far below the need for new trail bridges in the districts (Appendix C). The location allocation of these additional new trail bridges will have significant effects on the spatial patterns of improved accessibility as well as the spatial interaction between the village communities and social service centers.

1.3 Research Objectives

In Nepal, since 1990, when the Main Trail Study (Section 2.3.2) was completed, production of trail maps, transport infrastructure maps (printed paper maps) and database management in the trail bridge sector program have improved to a considerable extent. In particular, the choices of different thematic maps available in the market and mapping activities within development projects and planning institutions have increased during recent years. Trail bridge inventory databases are also developed for recording the attribute data of trail bridges. These maps and the trail bridge inventory database are the basic planning tools presently available in the trail bridge sector program in Nepal. However, there is no spatial integration and linkage of maps and attribute data that are required for enhancing decision making with respect to the optimal location for additional trail bridges and also for management of maintenance activities of the existing trail bridges. These two features of geographic information are stored and maintained separately and independent of each other. Hence, there is a requirement to integrate these databases using Geographic Information System (GIS) technology which further provides information for spatial analysis to facilitate location- and resource-allocation decision making.

The present research discusses the evolution of pedestrian trail bridge building practices in Nepal and their contribution in rural development efforts, but the main focus is on the application of GIS in optimizing the location allocation of trail bridges. This thesis outlines a methodology for linking spatial data with the attribute data of trail bridges for analysis with GIS technology and also proposes the integration of the spatial and attribute databases that will meet the requirement of transport-orientated spatial databases. Trail bridge planning, site selection, and program monitoring tasks can be executed more efficiently and cost effectively using GIS applications with their spatial information layers. Also, anchoring the inventory of trail bridge data with the spatial databases will enhance program coordination and management of maintenance tasks of the trail bridges built in the past years.

The goal of the research, using GIS related methods and techniques is, to identify poorly served areas and make an accessibility analysis of existing social service centers for the purpose of planning trail bridges. In order to achieve the thesis goal the specific objectives are defined as follows:

- to create digital base maps of one of the administrative districts based on recent transport infrastructure maps and central service maps (paper maps), and attribute data of trail bridges, road networks and social services;
- to develop linkages between the spatial and attribute databases of trail bridges, social services and settlement villages;
- to assess people’s interaction and existing accessibility patterns to social services;
- to propose an approach of optimizing the location of additional new trail bridges to provide “best” links to improve accessibility to social services.

The outcome of the first two objectives of map creation and integration of spatial and attribute data will be the basis for accessibility analysis for the third and forth objectives. Integrating the spatial and attribute databases using GIS applications provides a significant departure from traditional applications of paper maps and attribute lists. GIS technology offers many benefits to planners besides the basic objective of planning, monitoring and coordination of the trail bridge program. The database capabilities of a GIS make it an important tool for analyzing both the spatial and non-spatial components of databases.

1.4 Expected Research Contributions

Accessibility to social services is one of the basic ingredients of improved living conditions for people in the rural areas in Nepal. Trail bridges contribute to socio-economic development of the country by providing safe and reliable access for the people to social services and markets centers. Planning, selection of trail bridges, use of appropriate technology and allocation of resources for their implementation has always been a challenging task in Nepal and requires an efficient management tool to support decision making.

This thesis makes several contributions. From a practical perspective, the use of GIS applications facilitates efficient and effective decision making in planning and monitoring of trail bridges. The adoption of the GIS-technology planning system will enhance the decision- making process in the sense that many public planning organizations already possess or intend to acquire GIS capability. In addition, this thesis offers insight into the interaction between the settlement villages and social service centers, origin-destination travel and accessibility patterns and suggests an approach for optimizing the location of additional new trail bridges to improve accessibility to social services. It is anticipated that the results of this research would be applicable generally in trail bridge planning and would add to knowledge about understanding the spatial interaction of rural communities with the essential social services using interaction modeling tools in ArcGIS.

1.5 Organization of the Thesis

The thesis is organized in five chapters. Chapter One introduces general rural accessibility issues and transportation in developing countries. This chapter further discusses the important role and contribution of trail bridges in providing access to social services particularly in the rural areas in Nepal. It outlines the present research objectives and expected research contributions, and ends with the organization of thesis.

Chapter Two establishes the research context and provides a literature review relevant to the development of this thesis. It reviews some spatial analysis models (location allocation, gravity model, etc.) relevant to transportation planning and practices, and GIS applications related to planning of trail bridges. It provides a brief historical overview of the development and evolution of the bridge building knowledge and technology in general, and the trail bridge building practices in Nepal, in particular. It further describes the specific circumstances and the contributions of trail bridges to rural development efforts by providing basic accessibility to social services for the people of Nepal.

Chapter Three describes the study area, data sources and research methods. It provides background information about the country context (Nepal), study area, location and its geography (physical and human). It introduces the physiographic condition of the country, socioeconomic development indicators, development of transport infrastructure and accessibility to social services. It reviews the existing spatial and attribute databases and their scope of application in trail bridge planning. It further describes the scope of using GIS applications in trail bridge planning. Finally, methods for spatial data creation and integration, spatial interaction, accessibility and network analysis, using ArcGIS applications for the research described.

Chapter Four presents the results and analysis for the research objectives using ArcGIS applications. Outputs of the results from the existing accessibility patterns and analysis are presented first. This is followed by an analysis of the optimization of location allocation of additional new trail bridges to provide best links to improve accessibility to social services.

Finally, Chapter Five discusses and summarizes the findings of the research. It discusses the advantages of using GIS applications to enhance and facilitate efficient decision making in planning of trail bridges. It also suggests areas for future research. The chapter ends with implementation aspects of the research outcomes and possible problems (implications) that need to be addressed and considered in implementation.

The Appendices contain database documentations, ArcGIS-derived maps, and diagrams that complement the outcomes of the results and analysis.

Chapter 2
RESEARCH CONTEXT/LITERATURE REVIEW

This chapter reviews research relevant to the development of this thesis. This chapter is organized into three sections. The first section reviews the concepts and methods for understanding transportation decisions. It reviews conceptual frameworks of spatial analysis and location allocation models in improving geographical accessibility planning of rural services. The second section of the chapter shifts the focus to applications of GIS technology as a tool to facilitate decision making in transportation planning. The third section introduces the history and development of bridge building technology and practices as an important component of rural transport infrastructure in Nepal. It further discusses trail bridge building practices adopted in some different areas of the world. This section further reviews the existing planning tools for allocations of trail bridges and opportunities for GIS applications in trail bridge planning in Nepal. The discussion on the study area, data, methods and analysis will be expanded in chapter three.

2.1 Concepts and Methods for Understanding Transportation Decisions

2.1.1 Location Allocation

Social services and infrastructural facilities play an extremely important role in promoting development in rural areas. In particular, improving the access of rural population to essential social services is seen as a major instrument in accelerating regional development. The decision-making processes in developing countries and also in developed countries to certain extent are strongly influenced by historical, political and other considerations (Tewari, 1992). Nevertheless, it is still sometimes possible to use the principles of rational planning and spatial optimization in some transport infrastructure decisions. Indeed, several researchers (Ruston, 1984; Patel, 1979; Tewari and Jena, 1987) have concentrated on location-based approaches for planning social services and infrastructure in rural areas in developing countries.

From a spatial analysis point-of-view, markets and social service represent central places. Central place theory, as conceptualized by Losch (1954) and Christaller (1966), has provided the foundation for studies of spatial organization (Beaumont, 1987). This theory attempts to illustrate how settlements locate relative to one another; describes how villages, towns and cities function in a hierarchy of central places; and demarcates areas of influence for central services (Griesbaum, 2003).

Studies of central place theory were the conceptual basis for location allocation models (Griesbaum, 2003). A location allocation problem involves two basic elements: a set of consumers (population) distributed spatially over an area and a set of facilities to serve them (Taylor, 1983). Solving location allocation problems is essentially a geographical procedure of searching for spatial efficiency. Location allocation models, developed by operations research analysts, have been applied to a variety of locational planning problems in different contexts. Examples include siting public facilities, designing emergency service systems, analyzing spatial patterns of service delivery systems and also evaluating the efficiency of decision-making processes (Ghosh, 1987; Rushton 1987; Tewari and Jena, 1987). The goal of location allocation is to locate facilities so that they can supply the population in the most efficient manner, whether private facilities such as warehouses or retail stores, or public facilities such as libraries, fire stations or schools (ESRI, ARC/INFO, 2006). Location allocation is the process of determining the best or optimal location for one or more facilities so that the service or good is accessible to the population in the most efficient manner. These models optimize efficiency by simultaneously determining the configuration of the facilities (location) and assigning the people to the facilities (allocation), hence the term location allocation (ESRI, ARC/INFO, 2006).

Although location allocation models have long been used for assessing accessibility to goods and services, advances continue to be made in the use of these basic approaches for evaluation and planning of accessibility (Kwan et al., 2003). Kwan et al. (2003) further comment that there are many fundamental traditions in location modeling; two are prominent in recent accessibility studies. One tradition in location analysis is centered on maintaining stipulated maximum accessibility coverage. A second tradition focuses on minimizing average access (time or distance).

While early on, application of models were limited to finding locations that were optimal with respect to a single criterion from a relatively small choice set, later developments have led to solving problems involving multiple criteria and large numbers of potential locations (Tewari, 1987). The earlier attempts in location-allocation modeling also focused on normative analyses of well-defined location problems, while recent developments allow us to address complex behavior patterns (Ghosh and Rushton, 1987). Regardless, the main focus of the applications has been to develop analysis systems that will facilitate decision makers in their day-to-day decision-making functions (Densham and Rushton, 1987).

Rusthon (1984) argues that implementation of the relation between central place theory and service development planning proved to be impossible without the development of location allocation modeling methods. Location allocation models were seen as operational models and their use in India, Latin America and Africa preceded the recognition of their logical congruence with central place theory (Rusthon, 1988). A series of studies in Latin America have used location-allocation models to select locations to improve the proportion of the rural population that are within a given distance of primary health services (Rushton, 1984). Likewise, in a study in Africa (Burkina Faso in 1983) a location-allocation model was used to locate health service sites to minimize the aggregate distance traveled by the population subject to the constraint that no one would have to travel more than five kilometers distance (Rusthon, 1984). In India location-allocation algorithms were used to compute the locational efficiency of health service sites that had been selected in the past (Rusthon, 1984). Despite the view that location allocation models are too sophisticated for use in developing countries, analyses are possible in a great variety of situations (Maos 1983 as cited in Rusthon, 1984) and in several cases, comparisons with the results of other methods have shown the superiority of location allocation methods (Eaton, 1981 as cited in Rusthon, 1984).

Various software applications are available for identifying “optimal” locations. However, these are typically not available in local government offices, especially in developing countries. Therefore, alternative approaches using standard GIS software will, arguably, provide a more practical approach for rural accessibility planning in contexts such as rural Nepal. These alternative approaches include spatial interaction modeling and accessibility modeling, which can also provide “optimal” solutions to location problems”

2.1.2 Spatial Interaction and Accessibility

Spatial interaction means the movement of people, ideas and commodities within and between certain geographical areas (Fellmann et al., 2003). Interactions between an origin and a destination occur when demand for a commodity (service, goods, product) exists at one place and supply of the commodity at another place. Spatial interaction models represent the flows that occur between spatially separated origins and destinations (Kwan et al., 2003). Spatial interaction is a series of techniques used to compute or predict the number of interactions occurring between spatially separated places (Taylor, 1983).

The general spatial interaction model suggests that the interaction between two entities is proportional to their size and inversely proportional to the distance separating them (Wilson, 1967; Wilson, 1974 as cited in Horner, 2004). Interactions of places or activities are influenced by the friction of distance, cost or time which has a retarding effect on human interaction (Fellmann et al., 2003). The gravity model of spatial interaction can be used to analyze location-based accessibility (Fellmann et al., 2003). The name for this type of model comes from its historical origin as an application of Newtown's fundamental law of gravity in physical sciences. Newton's law of universal gravitation states that any two objects attract each other with a force that is proportional to the product of their masses and inversely proportional to the square of the distance between them. With the basic concept of the law of gravity, the force of attraction or pull F, between two bodies of respective masses M_i and M_j separated by a distance d_{ij}, will be equal to (Oppenheim, 1980 and Rich 1980):

$$F = g \frac{M_i M_j}{d_{ij}^2} \qquad \text{(Equation 2-1)}$$

where, g is a gravitational constant which ensures the equation is balanced.

The law of gravity thus sates that the amount of interaction exerted by two physical bodies on each other is proportional to their respective masses but also inversely proportional to the square of the distance between them (Oppenheim, 1980). In imitation of this gravity law of physics, the gravity concept of spatial interaction states in its simple term that the interaction between two areas numbered *i* and *j* (e. g. number of people living in area *j* who visit to social services in area *i*) will be directly proportional to the masses of these areas (their size, population level or level of attractiveness of the social services) but will be inversely proportional to some function of distance between them (travel time or cost of travel, travel impedance, etc.). Thus, the amount of interaction between the two areas will increase as the importance of these two areas increases but will decrease as the separation between them increases (Oppenheim, 1980).

In its general mathematical form the theory of gravity model can be expressed as the expected amount of interaction (I_{ij}) between two areas or places, *i* and *j*, is equal to (Oppenheim, 1980):

$$I_{ij} = k_i l_j O_j D_i F\left(d_{ij}\right) \qquad \text{(Equation 2-2)}$$

where, k_i is a factor related to area *i* and l_j factor related to area *j,* so the product $k_i l_i$ plays the role of *g* in equation (2-1). O_j is the measure of capacity for interaction originating at area *j*, and D_i is a measure of the capacity for interaction ending at area *i*. Finally, d_{ij} is a measure of separation or difficulty of interaction between space *i* and space *j*, and $F(d_{ij})$ is a mathematical function that represents the interaction impedance. Fellmann et al. (2003) use the following formulation of the gravity model replacing the physical mass with the population size (*P*) so that the expected interaction (I_{ij}) between two places located at a distance D_{ij} with population P_i and P_j can be expressed as:

$$I_{ij} = \frac{P_i P_j}{D_{ij}^{\;2}} \qquad \text{(Equation 2-3)}$$

In application of gravity model, the distances are generally calculated by travel distance, travel time or travel cost. The model assures that although spatial interaction always tends to decrease with increasing distance between places, at a certain distance it tends to expand with increases in their size (Fellmann et al., 2003). Studies in location theories suggest that the gravity model can be used to account for a wide variety of flow patterns in human geography including commodity flow, journey to work, travel for social services and the like (Fellmann et al., 2003). Each such flow pattern suggests that the size as well as the distance influences spatial interaction.

“Spatial interaction models of gravitational pull and friction of distance deal with only two places at a time” (Fellmann et al., 2003: 70). “The world of reality is rather more complex” (Fellmann et al., 2003: 70) as the cities or places have the possibility of interacting with each other. A potential model, which is also based on Newton’s law of gravitation, provides an estimate of the interaction opportunities available to a center in a multi-centered network (Fellmann et al., 2003; Rich, 1980). The potential interaction may be of goods, different forms of telecommunication and a whole range of social and economic contacts. The potential model tells us the relative position of each place in relation to other places within a geographic region. The potential model estimates the interaction opportunity by summing the potential created at a point by all the masses in a network system (Rich, 1980). Potential models can be used to measure accessibility by determining the spatial distribution of potential destinations, the ease of reaching each destination and quality and character of the activities or services available (Handy et al., 1997).

Harris (1954) and Hasen (1959) provide a foundation for modeling potential accessibility based on gravity concept and this approach has a long history with many applications (Hansen, 1959; Ingram, 1971; Patton, 1976; Vickerman, 1974; Wilson, 1971). Gravity-based accessibility measures are derived as the opportunities of interaction between places and generally influenced by an impedance function of travel time, travel distance or travel cost (Handy, 1997). The potential accessibility to services at a particular location is given by the attractiveness of each services weighted by how far away it is, so that distant services have little influences compared with opportunities nearby (Hayes et al., 2003). Potential accessibility, A_i for people of zone i (settlement village) can be measured as (Harris, 1954; Hansen, 1959; Rich, 1980):

$$A_i = \sum_{j=1}^{m} D_j \, f\left(C_{ij}\right) \qquad \text{(Equation 2-4)}$$

where, D_j is the attraction or activity at the j_{th} zone (place), and $f(c_{ij})$ is some impedance function of distance between locations, travel time or cost from locations i to j. The D_j term can reflect population, employment, or availability of social services (health services, education, post office and the like). The closer the opportunity or service, the more it contributes to accessibility; the larger the opportunity, the more it contributes to accessibility (Handy, 1997). Potential accessibility may be viewed as an index of the nearness of people or locations to one another, a measure of the influence of people at a distance, or the intensity of possible contact between people at *i* and facilities at all other locations *j* (Rich, 1980). Thus, Equation D gives a measure of the relative accessibility of people in zone *i* to the facilities or services in all parts of the area being examined.

2.1.3 Applications in Accessibility Planning

All spatial models consist of origins (consumer community), destinations (facilities) and flows between. With a location-allocation model, some of the origin/destinations or some of the links are not fixed and are thus focus of the exercise. In the gravity model, origin, destination and the link (distances) are fixed, and the focus is predicting spatial flows. The potential accessibility model is similar to the gravity model in that origins and destinations are fixed and the models are based on the attractiveness of locations and the distance between them (Rich, 1980), but rather than predicting spatial flows and focus is on quantifying potential flows.

2.2 GIS Applications in Transportation Planning

2.2.1 GIS Applications

The manipulation and analysis of spatial data are tasks frequently encountered by planners. For decades these processes involved manual handling of spatial data stored in the form of map sheets and were both difficult and expensive (Marble and Amundson, 1988). Over the past two decades the computer- based, GIS has developed as the primary technology for spatial data handling (Marble and Amundson, 1988). Planners use GIS as an analytical tool for solving specific problems, most often on a project related basis (Marble and Amundson, 1988).

GIS applications are being applied increasingly to a variety of pressing human and natural problems including infrastructure planning, resource management, and public service provision among others. GIS applications are becoming more popular amongst professional planners, mangers and decision makers (Yeh and Batty, 1990). GIS comprises a software product to carry out well defined functions (GIS software); digital representation of various aspects of geographic world in the form of datasets (GIS data); a computer hardware platform (computer); a community of people who use these tools for various purposes (GIS user community, institutional arrangement); and the activity of using a GIS to solve problems (doing GIS) (Longley et al., 2005). Three major aspects of GIS include cartographic ability, database management as well as analysis and modeling (Maguire, 1991).

GIS can be defined in many ways:

> "Geographic Information System is a computer system that captures, stores, manipulates, queries, analyzes and displays geographically referenced data. Among the diverse set of tasks a GIS can do, mapping remains the primary function" (Wang, 2006).

> ESRI (1999) defines GIS as "… a computer-based tool for mapping and analyzing things that exist and events that happen on earth. GIS technology integrates common database operations such as quarry and statistical analysis with the unique visualization and geographic analysis benefits offered by maps".

The key skill involved in GIS applications is the management of spatial and non-spatial attribute data and the linkage between them (Wang, 2006). An underlying principle of GIS is the ability to overlay different kinds of information for a specified geographic area, such as transportation networks, distribution of facilities and demographic data, so that the relationship between them can be assessed (Nicholls, 2001). The advent of GIS has greatly facilitated the storage, updating, retrieval and display of spatial data that were previously maintained on paper (Klosterman, 1995). GIS enables users to assemble, store, manipulate, visualize and display geographically referenced data more effectively. GIS uses computerized mapping and information system to combine spatial data with associated attribute data to facilitate spatial data analysis for improved decision making.

A review of literature indicates three general planning applications of GIS: information inventory maintenance, spatial information analysis and information presentation. In the literature of GIS use in planning, one frequently observed point is that GIS are very useful for enhancing information inventory functions previously managed manually. Two major benefits for planners are noted. First, the process of creating and maintaining information is more efficient. There is a great enthusiasm for efficiencies gained over use of manual records and paper maps which are expensive to prepare, hard to store and very difficult to maintain, update and analyze (Klosterman, 1995). Second, storage of planning information in GIS encourages representation of different data sets in a common format, easing comparison and data exchange. In the past, information pertinent to planning often has been maintained and stored in diverse jurisdictions and data formats making it hard to gain access and compare different components. GIS information inventory capabilities provide a system allowing information to be assembled into a single database (Marble and Amundson, 1988). Both information inventory benefits do not alter planning activities using manual methods, but rather reduce allocation of resources to routine record keeping and manual information processing for comparison, allowing planners to gain more through understanding that benefit and support decision-making. Another important application of GIS use in planning is the use of spatial analysis functions to improve understanding beyond the manual spatial analysis methods. The ability of GIS to deal with the spatial relationships are extremely useful for spatial analysis functions such as spatial interaction modeling related to transportation planning issues (Klosterman, 1995).

GIS technology is attracting a great deal of interests in both the industrialized and developing countries (Klosterman, 1995). This interest reflects the technology's demonstrated utility for a wide variety of geographically related applications (Klosterman, 1995). There are many professionals and organizations around the world that design, develop, expand or improve the spatial data management systems. GIS has become an integral tool for government, private and non-governmental organizations in developed countries. GIS technology has been introduced to many government and non-government agencies in developing countries in the past decade and the rate of adoption of GIS software in the developing world is increasing (Hall et al., nd). There are certain constraints in application of GIS in developing countries, such as absence of useable geo-referenced and up-to-date databases, lack of financial and trained human resources (Hall et al., nd). Analysis of the distribution of GIS installations worldwide by continent revels that approximately 65 percent in North America, 22 percent in Europe, 5 percent in Australia and 8 percent combined in South America, Africa and Asia (Mooneyhan, 1998). This distribution shows relatively low GIS installations in developing countries. GIS systems are expensive to install and maintain (Klosterman, 1995). The cost of cleaning existing data, converting it to digital form and filing the data gaps and deficiencies is usually larger than the combined cost of hardware and software (Klosterman, 1995). With the generosity of pricing policies and international collaborations GIS capabilities are increasingly being implemented in developing countries and educational institutions in the recent years (Mooneyhan, 1998). In most cases, the funding of GIS installation and development in developing countries relies on international funding and cooperating agencies.

The evolution of spatial information system has provided increasingly useful decision support in planning and resource management (Kliskey, 1995). Their development includes the evolution of thematic mapping and the use of GIS in spatial analysis as decision support tools. Resources or services are scarce and their efficient spatial distribution needs careful planning. A comparison of the functionality of different spatial information systems (Table 2.1) highlights the relative value of GIS in supporting planning functions (Kliskey, 1995).

Table 2.1**:** Functionality of applications of spatial information systems in planning

Ability of different spatial information systems to provide functionality for planning (ranging from low to high significance)		Spatial Information Systems Applications		
		Traditional paper Maps	Computer Cartography	Geographic Information System
Functionality in Planning	Communication	High	High	High
	Inventory	Moderate	High	High
	Monitoring	Low	Moderate	High
	Modeling and Spatial Analysis	Low	Low	High

Source: Adapted from Kliskey, 1995.

2.2.2 GIS in Accessibility Planning

An important concept in spatial analysis is accessibility. Accessibility is a measure of the nearness to opportunities (Young, (1988). Accessibility refers to the relative ease by which the locations of activities such as social services, work and market centers can be reached from a given location (Luo et al., 2003). The simplest measures of accessibility are the topological measures which reflect the spatial barrier between populations and service centers. These measures state whether two points in space are physically connected by a transport link thus enabling movement between them (Young, 1988). Accessibility is also determined by the distribution of supply and demand and how these are connected in space. Accordingly, the issue of location analysis is well suited for GIS to address (Wang, 2006). Measures of accessibility can be based on network analysis; travel times or distances to service centers; the number of facilities within certain time bands; or gravity model formulations (Nutley, 1998).

GIS have been widely used in transport system planning and management. They provide transport system planners, policy makers and researchers with the platform for data creation, acquisition, management, data integration, data analysis and visualization. Accessibility analysis is spatial in nature and hence fits with the GIS environment, and implementation of these techniques can be facilitated by the use of GIS technology (Liu and Zhu, 2004). Gravity and potential models have been implemented in GIS for a wide variety of transportation planning applications (Liu and Zhu, 2004). ArcGIS ARC/INFO provides two commands, INTERACTION and ACCESSIBILITY that use gravity-model concepts. Accessibility computes how accessible a location is to other locations given the attractiveness of other locations. Interaction computes detailed levels of interaction between pairs of locations known as origins and destinations taking into account properties of the origin in producing a trip and destination properties of attracting a trip (ESRI, ARC/INFO, 2006).

2.3 Bridge Construction

2.3.1 History and Development

This section introduces a brief history and development of bridge building practices. Starting from the broad outline it focuses on trail bridges. The trail bridges discussed in this thesis are the bridge structures that are built along the pedestrian trails over river crossing locations and meant for movement of people and animal traffic.

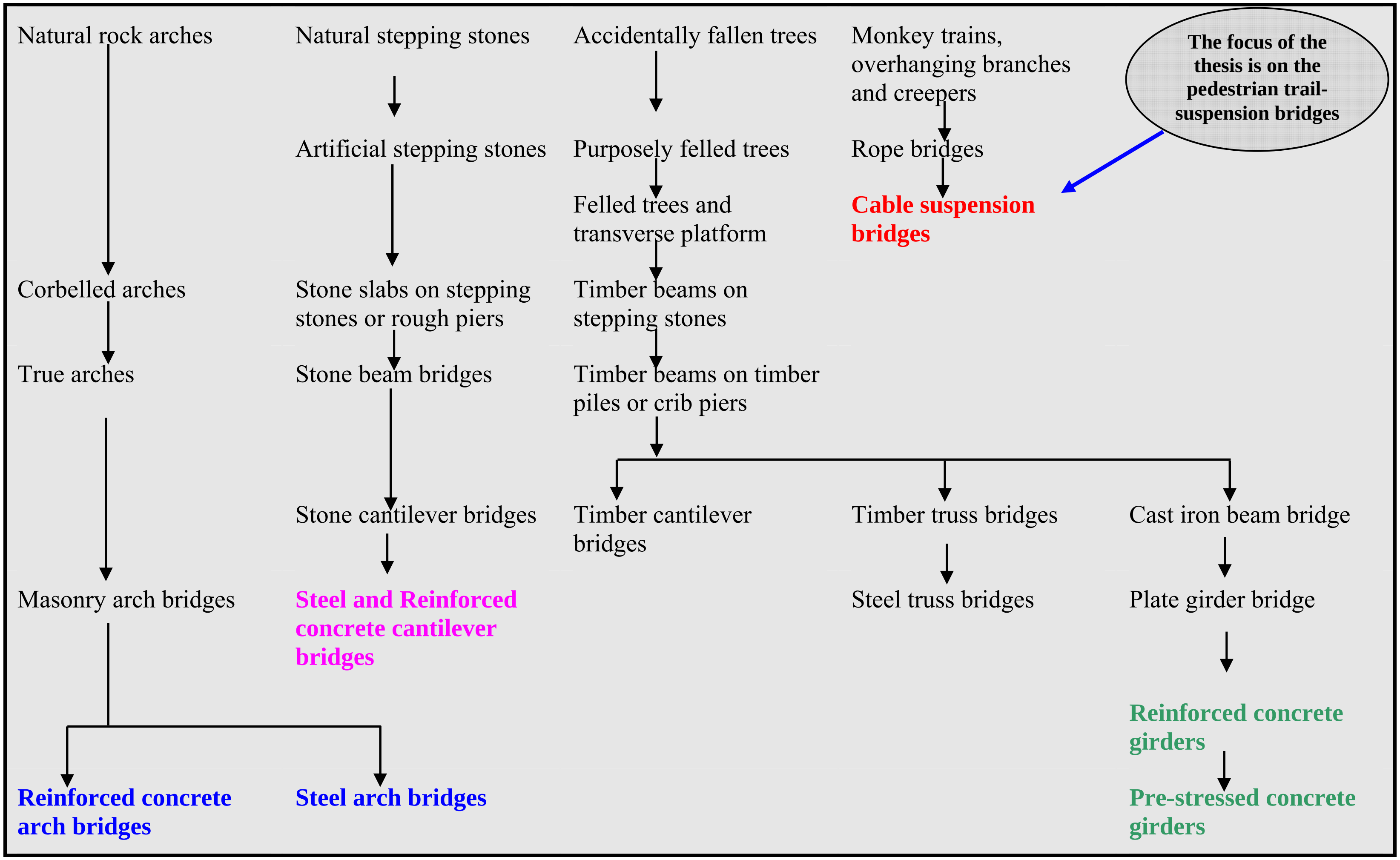
A bridge can be defined in many ways:

Andrea Palladio, the great 16th century Italian architect and engineer, spoke of the essence of bridge building "... bridges should befit the spirit of the community by exhibiting commodiousness, firmness, and delight" (Context for World Heritage Bridges, 1996).

Victor (1980: 1) defines a bridge as "a structure providing passage over an obstacle without closing the way beneath. The required passage may be for a road, a railway, a pedestrian pathway, a canal or a pipeline. The obstacle to be crossed may be a river, road, railway, or valley".

The history of the development of bridge construction practice is closely linked with the history of human civilization (Victor, 1980). In the foothills of mountains, rope bridges span deep gorges and fast flowing streams to maintain foot-trails from village to village for hill people. Such primitive and improvised rope bridges evolved from the vine and plant fibre (Figure 2-2) leading to the basic idea of modern suspension bridges. Sometime later, the simple wire rope and bamboo suspension bridges were devised, which later developed into the wire-rope suspension bridges. Such wire rope suspension bridges are in regular use for crossing rivers even today in the mountainous areas of China, Peru, Columbia, India, Bhutan and Nepal (Ryall, 2000).

Figure 2-1: Development of different types and forms of bridges



Source: Adapted from Victor, 1980.

Figure 2-1 illustrates the development of the various forms and types of bridges. From the point of view of structural functions, bridges can be classified into four basic types: beam bridges, arch bridges, cantilever bridges and suspensions bridges. These four bridge types have been known and built since ancient times and are the origins from which engineers and builders derived various combinations such as the truss, cantilever, cable-stayed, cable suspension, tied-arch, and moveable bridge spans.

Figure 2-2: Traditional and improvised but risky rope bridge over a river crossing in Nepal

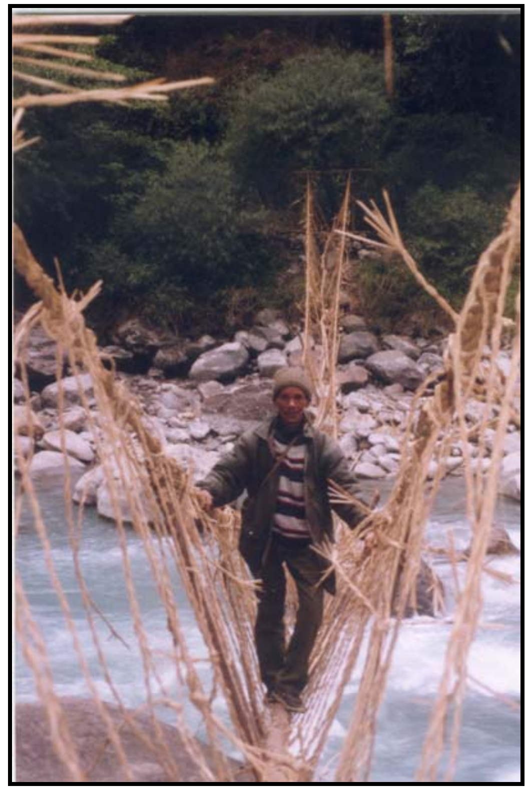


Photo source: Trail Bridge Section, Nepal, 2005.

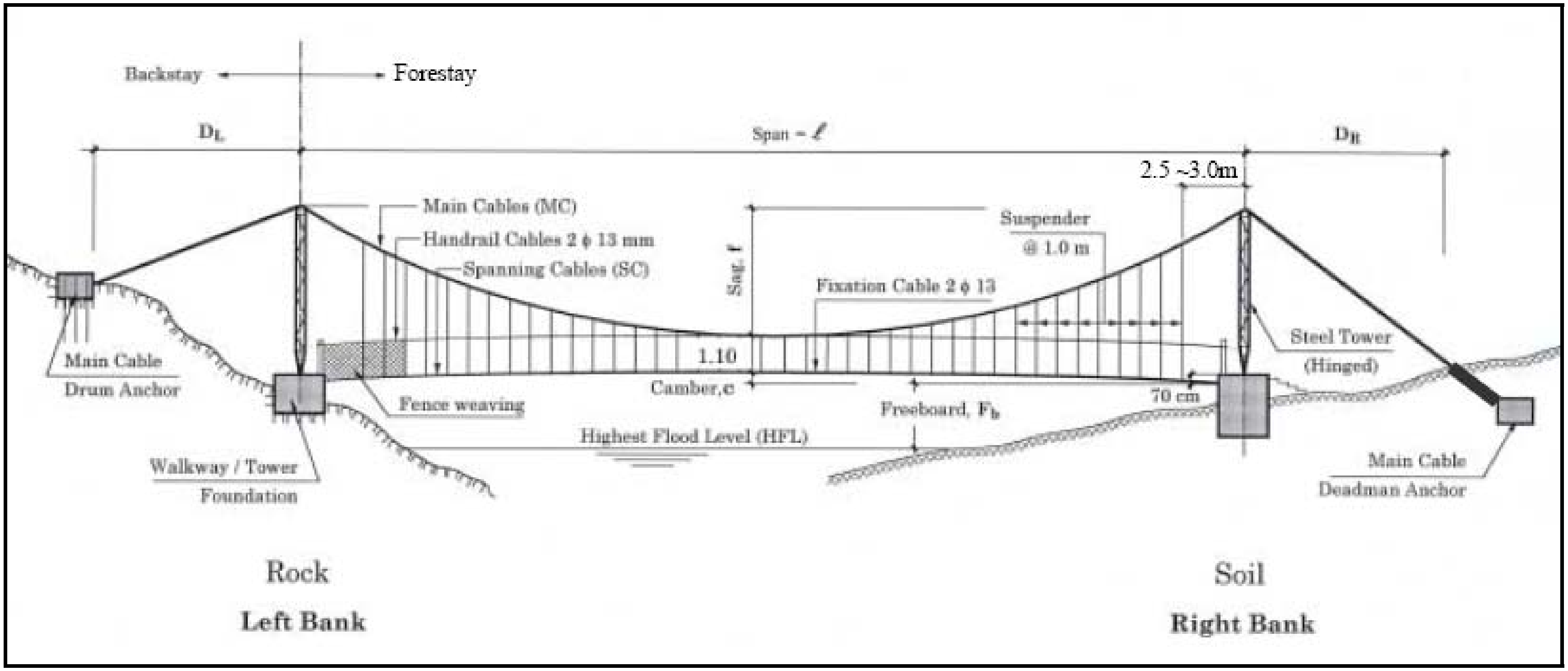
The earliest record of a bridge appears to be a bridge built across the Euphrates around 600 BC. The bridge linked the places of ancient Babylon on either side of the river (Bennett, 2000). In China it would appear that the bridge building evolved at a faster pace (Bennett, 2000). The method of crossing rivers using a flexible rope as a support appears to have originated in ancient times and was used by early civilizations in both the Central and South America, and the Far East and Asia (Jones et al., 2000). This was due to the local availability of natural fibres, from which ropes could be produced of sufficient strength to enable modest suspended span to be built (Jones et al., 2000). In Europe and North America, the construction of the first suspension bridges dates from the industrial revolution, when the wrought iron bars became available, from which chain cables could be manufactured. Chain cables were usually preferred for these early bridges because of their superior durability (Jones et al., 2000). Iron chain cable suspension bridges had been known as early as 206 BC in China. The world's first steel wire-cable suspension bridge was a 124 m (408 ft) footbridge built in 1816 over the Schuylkill in Philadelphia, USA (Context for World Heritage Bridges, 1996).

With the advances of science and technology, considerable achievements have been made in recent years building cable-supported suspension bridges. The principal structural elements of modern cable suspension bridges are provided below (Jones et al., 2000). Also, a general configuration of a pedestrian trail bridge in illustrated in Figure 2-3:

- two or more flexible main cables, which support the traffic carrying deck and transfer its loading by direct tension forces to the supporting towers and anchorages. These cables are formed from high strength steel wires.
- a traffic carrying deck structure, supported from the main cables by hangers constructed from high strength wire or strands or steel rods.
- towers to support the main cables at a level determined by the cable sag, combined by the clearance required above the waterway or other obstacle being crossed.
- anchorages to secure the ends of the main cables against movement. These structures must resist large horizontal forces.

Suspension bridges, when well designed and proportioned, are clearly the most aesthetically pleasing of all bridge types. The simplicity of the structural arrangement produces a naturally attractive structure. Such suspension bridges are a suitable choice for short span to relatively long span foot-bridges (Jones, at al., 2000). The Figure 2-3 provides a typical configuration of a pedestrian trail bridge.

Figure 2-3: General configuration of a typical pedestrian trail bridge



Source: Poudel, et al., 2003.

2.3.2 Applications of Pedestrian Trail Bridges in Different Countries

> "… An Indonesian mother dies during childbirth just short of the hospital. She lost too much blood during the12 hour detour getting around a flooded river crossing. Nepalese workers cannot cross the monsoon-swollen river to work on the other side, so the clothing factory closes, and more people are put out of work. An Angolan farmer has grain he cannot sell, so it rots in his field. Yet, he knows people are starving within eyesight across the rugged gorge. A bright Ethiopian cannot attend classes beyond grade 4, because an untamed river blocks the path between her and the upper school. Some of her friends have already drowned attempting to cross ……..…. Poor countries have very few bridges …"
> http://www.bridgestoprosperity.org/

This section summarizes the application, purpose, environmental and engineering considerations for planning of pedestrian trail bridges in different areas or countries. The primary objective of construction of a pedestrian trail bridge across a river is to provide means of safe access for the people and animals (Victor, 1980). It has been observed that the purpose, engineering and environmental considerations of trail bridge construction practices varies depending upon their applications and country context (Table 2.2). In some countries pedestrian trail bridges (for instance in Nepal, Bhutan, Ethiopia, Tanzania and Peru) are constructed to provide basic access needs of especially for rural people to improve their living conditions. In some countries (for instance in Canada and USA), these trail bridges are constructed to provide access to parks, recreation and conservation areas (Department of Transportation, 2006, New Brunswick, Canada; United States Geological Survey, 2006). Trail bridges are also constructed to provide means of access for oil pipeline crossings, drinking water pipelines and irrigation canals (Appendix B). Due to environmental concerns there are instances of construction of oil pipeline crossings, in the recent years, under the river bed in western Canada (Bachand et al., 1998). In the USA, suspension bridges (cableways) are also constructed for making discharge measurements or obtaining water samples on rivers that are too deep or speedy and to monitor the river hydrology (United States Geological Survey, 2006).

In the course of time, trail bridge building technology and practices have evolved from primitive and improvised bridges constructed over narrow gorges to high technology bridges spanning wide rivers. The engineering and socio-economic considerations of planning and bridge site selection adopted in Nepal have been successfully transferred and replicated to Bhutan, Ethiopia, Peru and Tanzania as these trail bridges primarily serve to provide basic access needs of the people in the rural areas (Trail Bridge Section, Nepal, 2005). Also, advances made in the trail bridge design, innovation made in the construction materials- and technology in the trail bridge sector program in Nepal can be replicated in other countries in the region and elsewhere. Of course, some adjustments to the local environment and landscape are required.

There have been considerable advances and achievements in engineering design, technology innovation and construction methods and practices in trail suspension bridge construction. Advances in design theory and better understanding of the strength and properties of materials by engineers were achieved in the years of trail bridge building practices. Spanning greater distances over wider rivers is a distinct measure of engineering achievement. Construction of durable bridges (design service life of 50 years for trail suspension bridges) providing safe and comfortable river crossing facilities for the people and also for pack animals indicates performance in the trail bridge sector. Introduction of the pre-stretched steel wire ropes and galvanized steel materials in the bridge superstructure enhances longer service life and also reduces recurrent maintenance costs.

Topographic maps, air photos and remote sensing images and other data provide information base and applications of GIS technology support for decision making for planning and bridge site selection. Applications of bio-engineering techniques, which combine an understanding of engineering principles with knowledge of vegetation and its interaction with soil, water and climate (Freer, 1991), are becoming more effective at slope protection and surface water management in trail bridge construction.

Table 2.2**:** A summary of pedestrian trail bridge planning considerations and applications in different countries

Location	**Environmental considerations**	**Engineering Considerations**	**Traffic**	**Purpose, Applications**
Nepal[1]	Initial Environmental Examination; emphasis on geological considerations in site selection	Span upto 350 m, Walkway width upto 1.20 m Safety factor for wire cable 1:3 Multi-span Cable suspension type Steel truss	People, Pack animals Drinking water pipes and irrigation pipelines	Provide the basis access needs of people to improve the living conditions
Bhutan[2]	Emphasis on geological considerations in site selection	Span upto 350 m, Walkway width upto 1.20 m Safety factor for wire cable 1:3 Multi-span Cable suspension type Steel truss	People, Pack animals but often used for crossing of small farm tractors	Address the transport needs of the rural community even in remote areas, by providing easier access to other communities, market, health, administrative facilities and services
Ethiopia[3]		Span upto 120 m Walkway width 1.06 m Safety factor for wire cable 1:3 Cable suspension type	People, Pack animals	Allow people to cross geographical barriers like rivers/gorges/mountains, thereby allowing access to schools, hospitals, and markets.
Tanzania[6]		Span upto 120 m Walkway width 1.06 m Safety factor for wire cable 1:3 Cable suspension type	People, Pack animals	Allow people to cross geographical barriers like rivers/gorges/mountains, thereby allowing access to schools, hospitals, and markets.

[1] Trail Bridge Manual, Trail Bridge Section, Nepal, 2003

[2] Suspension Bridge Program, Bhutan, http://www.helvetas.org.bt/sbp.htm

[3] Bridges to Prosperity, http://www.bridgestoprosperity.org/

A summary of pedestrian trail-bridge planning considerations and applications in different countries contd…

Location	**Environmental considerations**	**Engineering Considerations**	**Traffic**	**Purpose, Applications**
Peru[8]		Span upto 120 m Walkway width 1.06 m Safety factor for wire cable 1:3 Cable suspension type	People, Pack animals	Allow people to cross geographical barriers like rivers/gorges/mountains, thereby allowing access to schools, hospitals, and markets.
Canada[4]	Multi-span bridges require Environmental Impact Assessment	Walkway width upto 1.68 m, Multi-span Cable suspension type Steel beam Treated wood stringer	People, Oil pipeline	Access to road, along foot trails Natural parks and conservation areas Oil pipeline crossing
United States[5] (United States Geological Survey)	Design for 100 year flood return period	The USGS uses a ratio of 1:5 factor of safety in a wire rope, Single span, Cable suspension type Galvanized steel materials	People	Cableway bridges are used for making discharge measurements, to gauge stream flow or obtaining water samples on rivers in remote areas of the United States

[4] Department of Transportation, New Brunswick, Canada, http://www.gnb.ca/0113/footbridges/footbridges-e.asp

[5] United States Geological Survey (USGS) , http://wwwrcamnl.wr.usgs.gov/sws/cableways/descr.htm

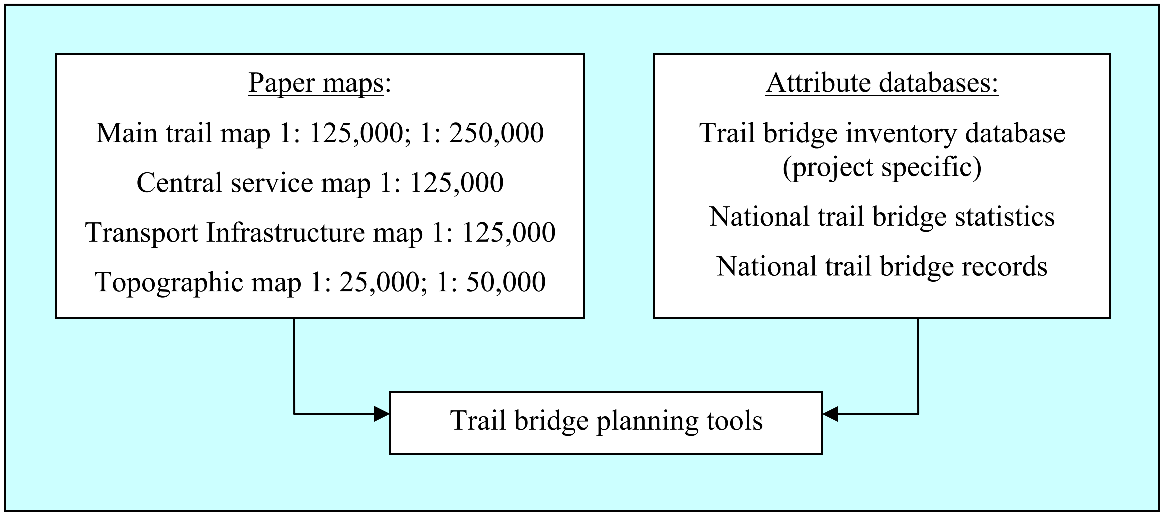
2.3.3 Planning Tools for Allocation of Trail Bridges in Nepal

Where roads are non-existent, goods are carried by people or pack animals on pedestrian-trails. Out of a large number of pedestrian-trails most of them are of local importance and serve mobility purpose of local communities. To make all the foot-trails functional through out the year, trail bridges are to be constructed over all the river crossing locations along these trails. The demand for construction of trail bridges is always high as compared to the available resources and capacity for implementation by the organizations involved in the trail bridge sector program. There was a need for a planning tool to facilitate prioritization and location allocation of trail bridges as Nepal's trail bridge program was expanding in the 1980's.

In order to keep the demand for trail bridges within a reasonable limit and develop a planning tool, Main Trail Studies[6] were undertaken in late 1980's to identify the major trade routes and river crossings requiring trail bridges (Trail Bridge Section, Nepal, 2005). The approach of the studies was a functional one based on distribution of population, social services, central places and the pedestrian trail network. These studies led to the production of the Main Trail Maps and Central Service Maps (Figure 2-5) later upgraded to the Transport Infrastructure Maps (Figure 3-9). The more important publication for the transport sector was that these maps provide information on roads, main trails, local trails, and river crossing locations that include main trail bridges and local trail bridges, and central places (Ministry of Local Development, Nepal, 2005). Over the years these maps became useful for planning not only for trail bridge planners and builders but also for agencies building roads or wishing to link roads into the trail network, as well as for trekkers.

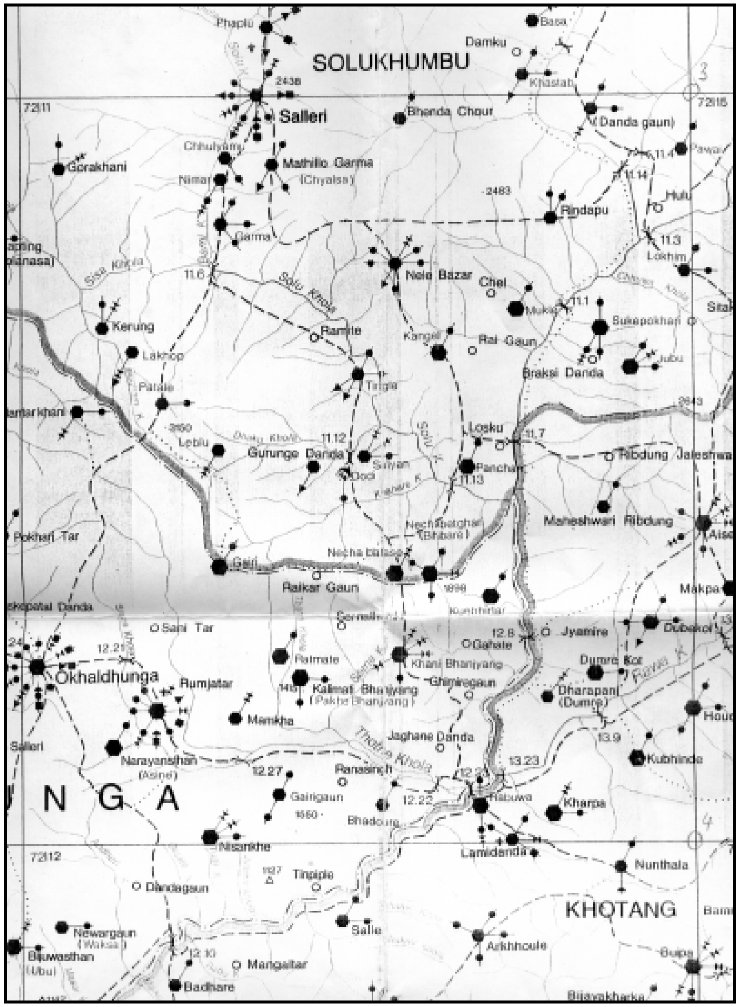
[6] Main Trail Studies: Comprehensive studies conducted by the Suspension Bridge Division of the Government of Nepal during 1989-1990 with the objective of determining main trails in order to provide a planning basis for pedestrian trail bridges. The determination procedures followed a functional approach related to the existence of social services such as educational, health, communication, transport, electricity, trade, industrial, banking, administrative, agricultural, tourism and religious facilities and the density of population. The hierarchy of places was graded on the basis of concentration of social services and their population (Griesbaum, 2003).

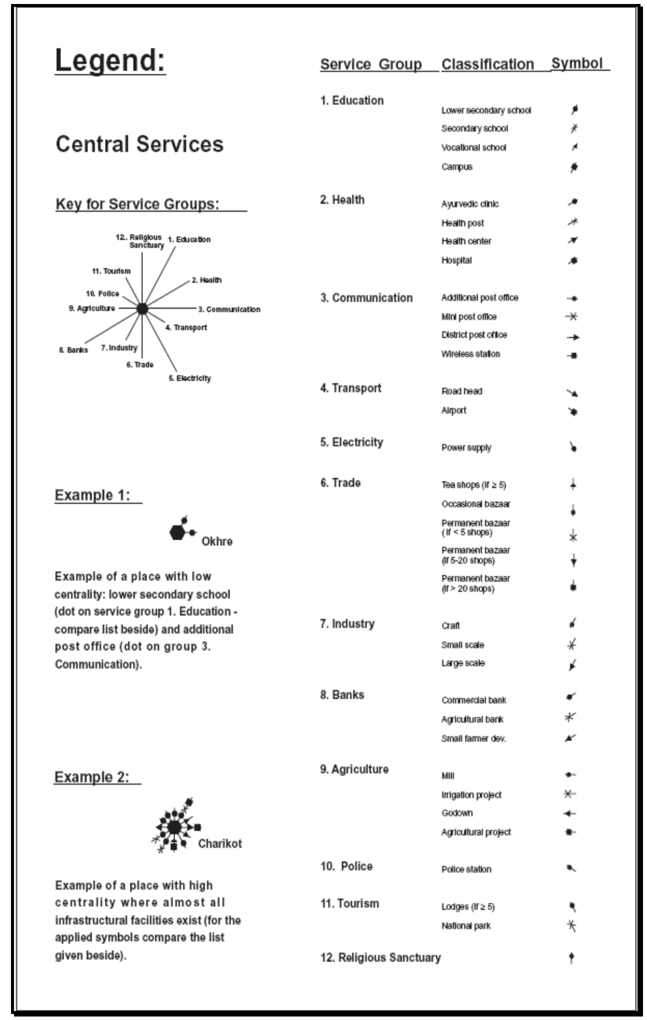
Figure 2-4: Trail bridge planning tools in current practice in Nepal



Complementary to the Main Trail Maps, the Central Service Maps contain additional information on the location and type of social service centers of 12 different types (education, health services, communication, transport, electricity, trade, industry, bank, agriculture, police, tourism and religious sanctuary) with symbol arrangements as shown in the legend in Figure 2-5 on district maps at the scale of 1:125,000. These maps also provide information about the centrality of settlement villages based on the concentration of social service centers and population.

Figure 2-5: Central Service Map depicting concentration of social service centers at different settlement villages



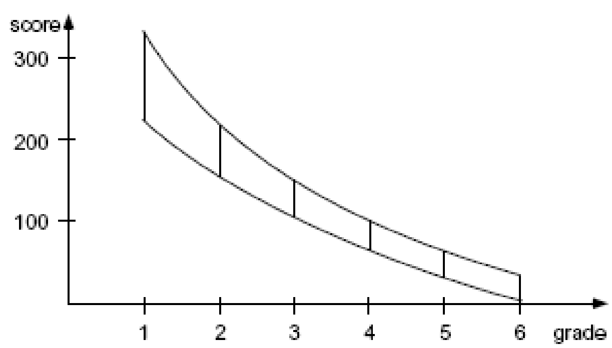


Map source: Trail Bridge Section, Nepal, 2005.

These trail maps helped to categorize trails as main trails and local trails in view of their utility and the importance of the places they linked (Nepal Trail Bridge Section, 2005). Main trails are defined as the trails connecting important locations which are graded based on the concentration of social service centers and the population density (Figure 2-6). The concentration and occurrence of social service centers and the population density define the importance of a place/village settlement. Trails linking important places/settlement villages like regional and district headquarters, road heads[7] are defined as main trails. These main trails not only provide access routes to district headquarters and important rural centers, they also link whole hinterlands with the road heads and domestic airports. All other trails of local importance that connect local communities in the close proximity are defined as local trails.

Figure 2-6: Grading scheme for places on Central Service Map

Central places		Score scheme
1. grade	most important places to be linked by a main trail	226 - 318
2. grade		153 - 225
3. grade	important places where a main trail should pass	103 - 152
4. grade		65 - 102
5. grade	less important place, not necessarily on a main trail	33 - 64
6. grade		4 - 32



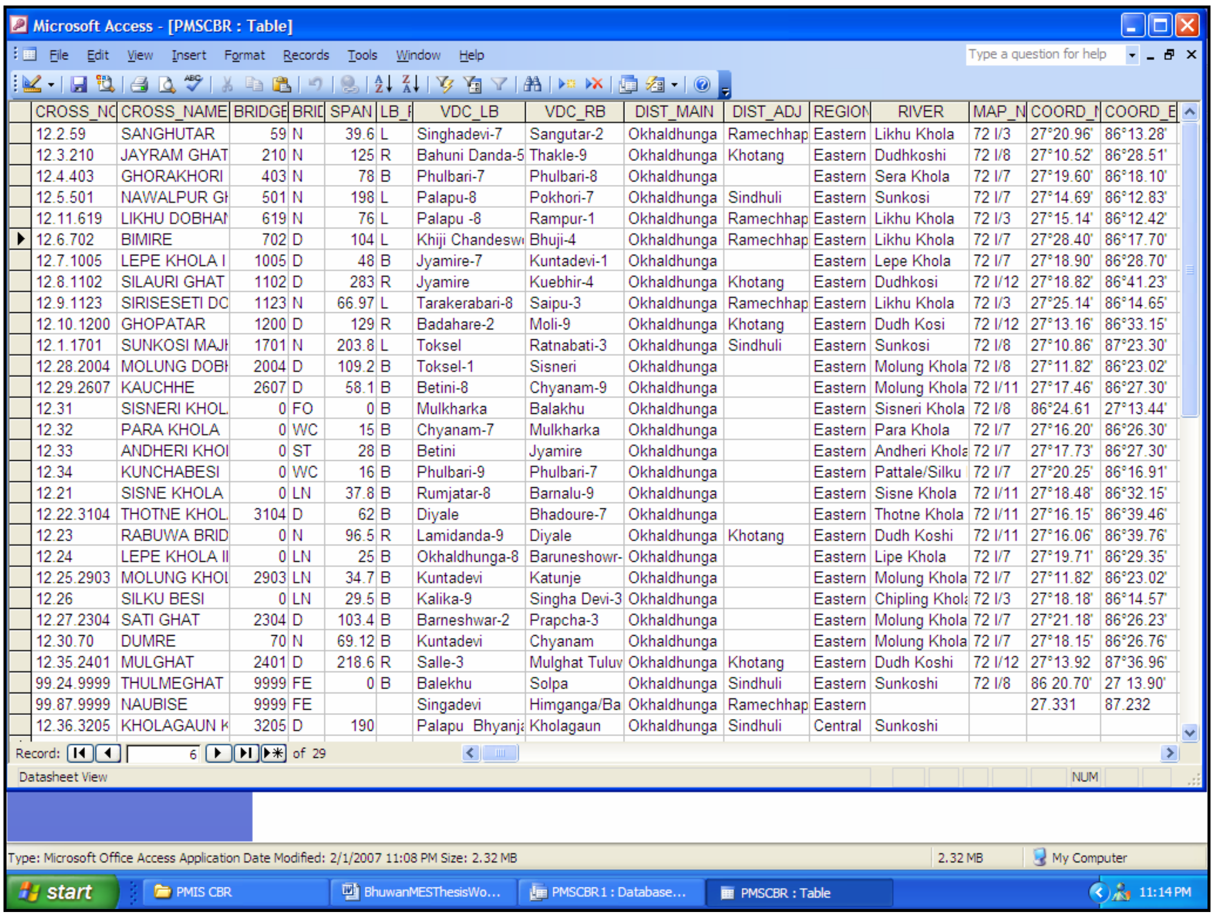
Service groups	Max. score
Education	60
Health	41
Communication	24
Transportation	20
Electricity	9
Trade	27
Industry	12
Banks	12
Agriculture	38
Police	9
Tourism	9
Religious Sanctuary	9
Population Density	50
Total	318

Source: Trail Bridge Section, Nepal, 2005.

[7] Road heads are node locations on the roads and highways that connect and provide access to other settlement villages and pedestrian trails located on the other side of the river or the hinterland.

Along with the development of the trail maps, a trail bridge inventory databases (Figure 2-7) was also developed for recording of all the river crossing locations. These databases and the trail maps (Figure 2-4) constitute the information base currently in practice for planning of additional new bridges and maintenance or replacement of the existing old bridges (Trail Bridge Section, Nepal, 2005; SDC, 2006).

Figure 2-7: A view of trail bridge inventory database in MS Access



CROSS_NC	CROSS_NAME	BRIDGE	BRID	SPAN	LB_I	VDC_LB	VDC_RB	DIST_MAIN	DIST_ADJ	REGION	RIVER	MAP_N	COORD_I	COORD_E
12.2.59	SANGHUTAR	59	N	39.6	L	Singhadevi-7	Sangutar-2	Okhaldhunga	Ramechhap	Eastern	Likhu Khola	72 I/3	27°20.96'	86°13.28'
12.3.210	JAYRAM GHAT	210	N	125	R	Bahuni Danda-5	Thakle-9	Okhaldhunga	Khotang	Eastern	Dudhkoshi	72 I/8	27°10.52'	86°28.51'
12.4.403	GHORAKHORI	403	N	78	B	Phulbari-7	Phulbari-8	Okhaldhunga		Eastern	Sera Khola	72 I/7	27°19.60'	86°18.10'
12.5.501	NAWALPUR GI	501	N	198	L	Palapu-8	Pokhori-7	Okhaldhunga	Sindhuli	Eastern	Sunkosi	72 I/7	27°14.69'	86°12.83'
12.11.619	LIKHU DOBHAI	619	N	76	L	Palapu -8	Rampur-1	Okhaldhunga	Ramechhap	Eastern	Likhu Khola	72 I/3	27°15.14'	86°12.42'
12.6.702	BIMIRE	702	D	104	L	Khiji Chandeswi	Bhuji-4	Okhaldhunga	Ramechhap	Eastern	Likhu Khola	72 I/7	27°28.40'	86°17.70'
12.7.1005	LEPE KHOLA I	1005	D	48	B	Jyamire-7	Kuntadevi-1	Okhaldhunga		Eastern	Lepe Khola	72 I/7	27°18.90'	86°28.70'
12.8.1102	SILAURI GHAT	1102	D	283	R	Jyamire	Kuebhir-4	Okhaldhunga	Khotang	Eastern	Dudhkosi	72 I/12	27°18.82'	86°41.23'
12.9.1123	SIRISESETI DC	1123	N	66.97	L	Tarakerabari-8	Saipu-3	Okhaldhunga	Ramechhap	Eastern	Likhu Khola	72 I/3	27°25.14'	86°14.65'
12.10.1200	GHOPATAR	1200	D	129	R	Badahare-2	Moli-9	Okhaldhunga	Khotang	Eastern	Dudh Kosi	72 I/12	27°13.16'	86°33.15'
12.1.1701	SUNKOSI MAJI	1701	N	203.8	L	Toksel	Ratnabati-3	Okhaldhunga	Sindhuli	Eastern	Sunkosi	72 I/8	27°10.86'	87°23.30'
12.28.2004	MOLUNG DOBI	2004	D	109.2	B	Toksel-1	Sisneri	Okhaldhunga		Eastern	Molung Khola	72 I/8	27°11.82'	86°23.02'
12.29.2607	KAUCHHE	2607	D	58.1	B	Betini-8	Chyanam-9	Okhaldhunga		Eastern	Molung Khola	72 I/11	27°17.46'	86°27.30'
12.31	SISNERI KHOL.	0	FO	0	B	Mulkharka	Balakhu	Okhaldhunga		Eastern	Sisneri Khola	72 I/8	86°24.61	27°13.44'
12.32	PARA KHOLA	0	WC	15	B	Chyanam-7	Mulkharka	Okhaldhunga		Eastern	Para Khola	72 I/7	27°16.20'	86°26.30'
12.33	ANDHERI KHOI	0	ST	28	B	Betini	Jyamire	Okhaldhunga		Eastern	Andheri Khola	72 I/7	27°17.73'	86°27.30'
12.34	KUNCHABESI	0	WC	16	B	Phulbari-9	Phulbari-7	Okhaldhunga		Eastern	Pattale/Silku	72 I/7	27°20.25'	86°16.91'
12.21	SISNE KHOLA	0	LN	37.8	B	Rumjatar-8	Barnalu-9	Okhaldhunga		Eastern	Sisne Khola	72 I/11	27°18.48'	86°32.15'
12.22.3104	THOTNE KHOL.	3104	D	62	B	Diyale	Bhadoure-7	Okhaldhunga		Eastern	Thotne Khola	72 I/11	27°16.15'	86°39.46'
12.23	RABUWA BRID	0	N	96.5	R	Lamidanda-9	Diyale	Okhaldhunga	Khotang	Eastern	Dudh Koshi	72 I/11	27°16.06'	86°39.76'
12.24	LEPE KHOLA II	0	LN	25	B	Okhaldhunga-8	Baruneshowr-	Okhaldhunga		Eastern	Lipe Khola	72 I/7	27°19.71'	86°29.35'
12.25.2903	MOLUNG KHOI	2903	LN	34.7	B	Kuntadevi	Katunje	Okhaldhunga		Eastern	Molung Khola	72 I/7	27°11.82'	86°23.02'
12.26	SILKU BESI	0	LN	29.5	B	Kalika-9	Singha Devi-3	Okhaldhunga		Eastern	Chipling Khola	72 I/3	27°18.18'	86°14.57'
12.27.2304	SATI GHAT	2304	D	103.4	B	Barneshwar-2	Prapcha-3	Okhaldhunga		Eastern	Molung Khola	72 I/7	27°21.18'	86°26.23'
12.30.70	DUMRE	70	N	69.12	B	Kuntadevi	Chyanam	Okhaldhunga		Eastern	Molung Khola	72 I/7	27°18.15'	86°26.76'
12.35.2401	MULGHAT	2401	D	218.6	R	Salle-3	Mulghat Tuluv	Okhaldhunga	Khotang	Eastern	Dudh Koshi	72 I/12	27°13.92	87°36.96'
99.24.9999	THULMEGHAT	9999	FE	0	B	Balekhu	Solpa	Okhaldhunga	Sindhuli	Eastern	Sunkoshi	72 I/8	86 20.70'	27 13.90'
99.87.9999	NAUBISE	9999	FE			Singadevi	Himganga/Ba	Okhaldhunga	Ramechhap	Eastern			27.331	87.232
12.36.3205	KHOLAGAUN K	3205	D	190		Palapu Bhyanja	Kholagaun	Okhaldhunga	Sindhuli	Central	Sunkoshi			

Data source: Planning and Monitoring System Database, Trail Bridge Section, Nepal, 2005.

There is a hierarchy of trail bridges that needs to be considered when planning for new construction. Depending on the spans of river crossing locations they are categorized as long-span and short-span trail bridges. Long-span trail bridges (bridge span > 120 meters) are built primarily on the Main Trails at a rate of up to 25 trail bridges per year. Although this is a significant improvement compared to the Scottish bridges that were built in early 1900's, it is still not enough to meet the high demand for additional new trail bridges connecting the numerous human settlements in rural areas. Moreover, the sturdy long span trail bridge designs are too costly for the short-span river crossings that are of local importance and connect local communities.

Consequently, at the request of many local communities, Helvetas developed another bridge type, modeled after traditional chain bridges (Figure 3-4a) that used to be built in the district of Baglung (one of the 75 administrative districts of the country) in western Nepal. The bridge type that emerged is based on reviving local traditional skills, optimizing local materials in order to ensure its replicability nation-wide (Trail Bridge Section, Nepal, 2005). Local communities reciprocated by submitting unprecedented requests initiating and undertaking the construction of local bridges. Spans for these community-bridges range from some 65 to about 120 meters. These trail bridges are constructed at the rate of up to 200 per year primarily on the river crossing locations on the local trails.

Social and engineering components of the trail bridge site selection procedures with community participation are well integrated in practice in Nepal. There have been many studies on socio-economic benefits of a trail bridge to the community but few studies examined the impacts of trail bridges on the land use patterns of the surrounding areas (Trail Bridge Section, Nepal, 2005). Studies on spatial analysis methods using Geographic Information Systems applications for trail bridge planning and site selection are also lacking. This indicates a gap and an area for research to examine the effectiveness of GIS applications in trail bridge planning. Hence, there is an opportunity to use GIS as a tool to enhance in decision making related to the selection of suitable trail bridge site for improving accessibility. Most importantly, the research efforts include applications of spatial analysis methods using GIS technology. GIS applications facilitate decision making by providing spatial reference integrating resource data related to social and technical aspects of the potential new trail bridges.

2.3.4 Using GIS for Trail Bridge Planning in Nepal

2.3.4.1 Existing Resources and Practices

The use of maps and air photos in development planning in Nepal started from 1970's with basically production of paper maps. The main authority for map production in Nepal lies with the Survey Department. The first series of topographic maps was the one inch to one mile map (scale 1:63,000) that was prepared in 1972 with the assistance of the Indian Topographic Survey. This series was restricted for public use so that it was extremely difficult to get access to such map sheets. The district maps, in 1:125,000 scale, were produced in 1986 on the basis of the one inch to one mile maps and for a long time this series constituted the only map available for the public. Special overlays for census maps were prepared at the same scale.

As a consequence of limited map availability for development planning, a study called the "Main Trail Study" (Section 2.3) was conducted by the Suspension Bridge Division[8] of Nepal to produce its own Main Trail Map (scales 1: 125,000 and 1: 250,000) especially required for the trail bridge planning. The Main Trail Maps document's most important features include central places, main trails, important local trails, and all types of trail bridges. Because of the lack of alternatives, the Main Trail Maps quickly became the primary information base for planning development projects (Trail Bridge Section, Nepal, 2005).

In view of the need to improve the maps in terms of content, management and updating and considering the development of mapping technology and also the availability of computer technology a second generation of the Main Trail Maps was developed and successively produced covering all the 57 hill districts[9] between 1998 and 2005. Named Transport Infrastructure Map (TIM), these maps are available for the public in print and in digital data format as Macromedia Freehand database. These maps are substantially improved compared to the previous series of maps in terms of

[8] Suspension Bridge Division: A division under the Ministry of Local Development of Nepal which is responsible for coordination of implementation of all trail bridge building programs in Nepal.

[9] Out of total 75 administrative districts, there are 57 hill districts in Nepal where trail-based transport system is more prominent.

information resources. Integration of these data into ArcGIS applications is planned for the near future.

In 1992, the Survey Department, with the support of FINNMAP (a program supported by the Government of Finland) started a new topographic base map program. The first map sheets were published in 1995, for the mid hills in 1: 25,000 and for northern remote areas in 1: 50,000 scale. New aerial photographs were taken from 1992 onwards which formed the main information base for development of these topographic maps. The mapping program was completed in 2002. The topographic map sheets for the whole country are available with the following thematic layers:

- administrative boundaries (district and village development),
- transport networks (includes roads and trails),
- settlement villages,
- land use and land cover,
- river systems,
- contours and spot heights,
- designated areas (parks, conservation areas, etc.), and
- utility service lines.

There are also some mapping projects within the International Centre for Integrated Mountain Development (ICIMOD[10]). The ICIMOD mapping activities mainly focus on small scales for the Hindukush-Himalayan Region. The themes are physiography, climate, demography, socio-economic characteristics, agriculture and hydropower systems. Many of these maps are published in small scales in atlas format such as “Districts of Nepal-Indicators of Development” or “Climatic and Hydrological Atlas of Nepal” (ICIMOD, 2001).

[10] International Centre for Integrated Mountain Development (ICIMOD), established in 1983 in Kathmandu, Nepal, serves eight regional member countries (Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal and Pakistan) of the greater Himalayan region and the global mountain community. As a mountain learning and knowledge centre, ICIMOD seeks to develop and provide innovative solutions, in cooperation with over 300 regional and international partners, which foster action and change for overcoming mountain people's economic, social and physical vulnerability (http://www.icimod.org/home/).

The first generation of Main Trail Maps (1989 -1995) was prepared by using manual cartographic methods, i.e., scribes sheets, positive films and combined films in a labor and material intensive method. In addition to all the features of the first series of the Main Trail Maps, the second generation maps called Transport Infrastructure Maps (1998 - 2005) includes also contour lines in 250 meters interval and locations of all types of trail bridges. The coordinate grid lines in the transport infrastructure maps are arranged in such way that each quadrant represents exactly the 1: 25,000 topographic FINNMAP sheet sizes, therefore enabling direct reference to these large-scale maps by the given identification number (topographic map number). Village development committee boundaries and headquarters and all trail bridges are further additions to these TIM. The digitization and finalization up to the stage of filmsetting was carried out in the graphic program Aldus Freehand. The transfer of these data into a geo-referenced program such as ArcGIS was envisaged by using the extension program MAPublisher that allows import and export of spatial data via shape-file creation or transformation into data exchange format- *.dxf (Trail Bridge Section, Nepal, 2005).

The first generation of Main Trail Maps (1989 -1995) and the most recent second generation of TIMs (1998 - 2005) serve as the information base for planning of transport services and accessibility to social services. Because of the scale (medium scale 1:125,000 and 1: 250,000), several districts can be shown on one map sheet thus providing the necessary overview across a larger area that is mandatory for inventories and network planning at the district and regional levels. This implies that basic information such as topographical features, administrative boundaries, trail and river networks, location of social services and transport infrastructure might be useful for other purposes of regional and local level planning as well. Nowadays, these data could be retrieved in a much more user-commanded manner, once the data are transferred and stored on ArcGIS-compatible database applications.

There has been significant progress in terms of development and utilization of digital maps and attribute databases for the planning of rural transport infrastructure and accessibility to social services in Nepal. A wide range of thematic maps, in different scales, ranging from 1: 250,000 to 1: 125,000 has been produced. A separate database of trail-bridges constructed in the past and the trail bridges in the implementation program are also maintained to monitor their conditions and construction progress respectively. Despite the substantial achievement in map production and database management in the trail bridge sector program, there is no spatial linkage of the spatial data (maps) and the trail bridge attribute database (aspatial data). These two elements of geographic information and data are stored and maintained separately (Figure 3-9, Figure 3-10) as there was no vision for integrating these in the early stage of development. The digital maps are stored in Macromedia Freehand file format while trail bridge databases are stored in FoxPro and MS Access database systems. The users have to analyze the relationships and make a decision based on the information available in the two different data formats. Hence, with the availability of GIS applications, there has been a requirement to integrate these data using a GIS technology to facilitate and enhance decision making process in the trail bridge sector development program.

2.3.4.2 Opportunities for GIS Applications

The 1990's witnessed the development of sporadic GIS activities in Nepal. The activities, however, were primarily focused on digital conversion of maps, without sufficient utilization of the whole range of utilities of geo-spatial data. Digital topographic database developed by the Survey Department, database developed under the United Nations Development Program (UNDP) such as Local Governance Project and Participatory District Development Project, ICIMOD and Helvetas are the major outcomes of these efforts. Besides, there were other smaller databases created by different organizations for their own specific purposes. Databases thus created were not envisaged to ensure data sharing and exchange but were primarily to respond to their specific needs of the organizations concerned. In 2002, the Government of Nepal initiated the National Geographic Information Infrastructure Programme with the objective of avoiding duplication in spatial data creation and usage through the networking of different Geographic Information systems in the country (Chhatkuli, et al., 2005). This initiative provides potential opportunities for data sharing and maximization of use of thematic reference data in GIS environment.

Given the wide range of applications of GIS in planning and increasing international collaborations, a number of agencies in Nepal are either using GIS or have indicated an interest in establishing GIS installation when resources become available (DFID, 2003). Agencies with an interest in GIS installation in Nepal include National Planning Commission, District Development

Committees and various international collaborating and private sector organizations (DFID, 2003). This indicates opportunities and perspectives to introduce GIS in planning and resource management practices in the district development programs in Nepal.

At present, GIS use in the trail bridge program in Nepal is limited to mapping applications. There have been considerable achievements in the recent years in the production of digital maps and inventory databases of trail bridges and other related services and facilities for rural development planning. There are opportunities and scopes, with the increasing collaboration among the development organizations involved in rural development programs in Nepal, to share, exchange and integrate these spatial and non-spatial databases using GIS applications. The present limitations tend to reflect a need to develop capacities of planners and decision-makers at the district level.

GIS applications in trail bridge location allocation will provide planners and decision makers with opportunities to enhance planning and management of infrastructure facilities which includes trail bridges and social services. The methods proposed in this research are relatively common and have been used in a wide variety of transportation planning applications. However, there have been no studies on the spatial interaction and potential accessibility modeling using ArcGIS with respect to river crossings and trail bridges, rural communities and social services. The present study facilitates identification of poorly served areas and population, and suggests where new additional trail bridges might be best sited in order to maximize access to social service centers.

Chapter 3

STUDY AREA, DATA SOURCES AND RESEARCH METHODS

3.1 Study Area

3.1.1 The Country Context and Geography of Nepal

Nepal is a landlocked developing country that lies in the Hindu Kush region of the Himalayas in South Asia. It is located between 26° 22' and 30° 27' north latitude and 80° 4' to 88° 12' east longitude. In the north, China extends over the high altitude plateau of Tibet. India surrounds Nepal in the east, west and south (Figure 3-1). Its economic development largely depends, on its political relations with neighboring countries and necessitates the maintenance of transport links. Nepal covers an area of 147,181 square kilometers which extends 885 km east-west and 145 to 248 km north-south. Across a relatively small latitudinal extent, altitude rises from 70 m asl (meters above sea level) to the world's highest peak (Mount Everest at 8850 m asl). The country is divided into five physiographic regions. From south to north with increasing altitude, these are (1) Terai[11] plains, (2) Siwalik Hills, (3) Middle Mountains, (4) High Mountains and (5) High Himalayas. These physiographic extremes are accompanied by extremes in climate. Temperature varies from as high as 48° Centigrade in the tropical Terai and to as low as minus 35° Centigrade in the Himalayas (Central Bureau of Statistics, Nepal, 2004).

The Siwalik Hills, Mountains and Himalayas cover approximately 85 percent of the land and present young geology, characterized by frequent landslides and earthquakes. This young geology coupled with adverse climatic conditions result in rugged terrain with countless rivers and streams. Often, during monsoon rains, whole valleys of the hinterland are cutoff from the road network to markets, other essential services and economic centers due to frequent landslides or damage of bridges by flood and debris flows. Due to natural factors (monsoonal climate, weathered rocks, and steep slopes) the entire mountain terrain is potentially unstable (Messerli, 1993). The Himalayan

[11] Terai is a narrow strip of about 15 km, fertile, densely populated plain land stretching beneath the lower ranges of the Himalaya located in the southern part of Nepal along the northern border of India.

mountain range is one of the most difficult regions of the world in which to build and maintain roads, trails, bridges and associated structures. Steep and complex terrain, fractured and weathered rock and heavy monsoon rains create conditions of severe natural instability. Also, man-induced effects of deforestation, poorly managed farming, and the construction of roads and bridges have an adverse effect on slope stability (Transport Research Laboratory, 2000). These conditions make development of transport infrastructure challenging and costly.

Figure 3-1: Location map: Nepal

Map source: http://www.mapquest.ca

The majority of human settlement located in the northern hilly and mountainous areas of the country and is not accessible by motorized vehicles. Given the topography and geology of the country this situation is likely to remain for many years to come. People in the northern hills and mountains rely on pedestrian foot trails and mule tracks, and they are used to walking days and sometimes weeks carrying essential things on their back to help them in their day-to-day survival. Motor vehicles, motorcycles or even bicycles are confined to the lowlands and are virtually absent in the hill and mountainous parts that dominate the country (Trail Bridge Section, Nepal, 2005).

Of the total population of 23 million (2001), 87 percent of the population lives in the rural areas where rural transport development is key to improving accessibility, and social and economic conditions of people (Central Bureau of Statistics, Nepal, 2005). Cross-country movement is slow, difficult and dangerous, and the cost of long distance spatial interaction is far higher in time and risk (Figure 3-2). An estimated 50 percent of Nepal's population lives at least four hours walk from the nearest dry-season road and only about 30 percent have access to all-season transport services (Transport Indicators Survey, World Bank, 2004). Inadequate rural transport services, therefore, is a major factor constraining the access and use of social services and markets by communities. Per capita incomes are 50 to 65 percent lower in the more remote far-west hill and mountain districts than they are in the relatively more accessible Terai plain terrain and central hill districts (Ministry of Local Development, Nepal, 2004).

Table 3.1 and Table 3.2 below provide a brief country profile of Nepal and comparison of some of the development indicators with Asia and the world respectively.

Table 3.1: Nepal-A Brief Country Profile

Geographic Location	
Location	South East Asia
Latitude [North]	26° 22' to 30° 27'
Longitude [East]	80° 4' to 88° 12'
Transport Sector	
Road network [km]	21,000
Road density [km/100 km^2]	14
Population influence per km road	1,100
Roads per capita [m]	1
Number of road-bridges built	1,100
Trail network, approx. [km]	60,000
Number of foot trail-bridges built	3,400
Number of airports (international)	1
Number of airports (domestic)	45
Railways [km]	59

Source: National Planning Commission, Central Bureau of Statistics, 2004, Kathmandu, Nepal.

Table 3.2**:** Some Human Development Indicators of Nepal and comparison with Asia and the World

Indicators	**Nepal**	**Asia**	**World**
Size [square km]	147,181	44,400,000	510,080,000
Population [million]	23	3,905	6,465
Population density [inhabitants/km^2]	157	123	48
Population growth rate [%]	2.25	1.20	1.20
Adult (15+) literacy rate [%]	48.6	79.3	82.2
Rural population [%]	87	40	49
Life expectancy at birth [yr]	61	67	67
% of Population under age 15	39	28	28
% of Population age 60 or older	6	9	10

Source: United Nations Department of Population and Social Affairs, Population Division, World Population, United Nations, 2005 and UNESCO Institute for Statistics, 2006.

Table 3.1 and Table 3.2 indicate that the majority of the population (87 percent) lives in the rural areas where road transport infrastructure and services are in the early stage of development or non existence. Road length per capita is about 1 meter. Railway service is insignificant (only 59 kilometers) which is available only in the eastern part of the Terai plain. Air transport is also not reliable and most of the domestic airports are seasonal (fair weather). Air transportation of agricultural and industrial goods as well as people is expensive in comparison to other modes of transportation (Griesbaum, 2003). Consequently, given the topographical features of the land and the present status of development of transport infrastructure and services, the pedestrian-trail and trail bridges are playing and will continue to play an important role in providing transport services to the communities in the rural areas in the foreseeable future.

Figure 3-2: Diverse conditions of pedestrian foot-trails and river crossings: People walking carrying their daily essential substances along pedestrian-trails (a), A person risking his life by crossing a flooded river (b), Porters helping each other to cross a gushing river c), and People and mules crossing a river on a pedestrian trail bridge with relatively safe and comfort (d).

Photos source: Trail Bridge Section, Nepal.

Nepal has always been an independent state. Until 1950 it remained closed to the outside world. It has made great efforts to at least attain the level of development of its neighbors in the South East Asia. But in spite of substantial progress, Nepal is still one of the poorest countries in Asia. A large part of its population of 23 million lives in isolated settlements in mountainous regions where access remains extremely difficult and about half of the population lives below the poverty line. Around 80 percent of the economically active people work in the agriculture sector which accounts for more than 40 percent of the gross national product. International development assistance, tourism, and exports of carpets and garments play an important role in the Nepalese economy, especially as a source of foreign currency. For the last ten years the remittances of millions of Nepalese working abroad have been crucial to achieve poverty reduction, maintain the external balances of trade and substantially increase the national saving rate (Swiss Agency for Development and Cooperation, Nepal, 2005). Since 1990 and up until the most recent events, Nepal has been a parliamentary democracy with a constitutional monarchy. Political instability, frequent government changes and inter-party conflicts have shaped the political scene over the past years. Planned decentralization aimed at transferring part of the competencies and responsibilities to the district and community levels is making only sporadic progress.

Nepal is a multiethnic state. In spite of the variety of origins, religions and languages, the people appear to live in harmony. Disadvantaged groups are politically underrepresented and their access to resources allocation and utilization is extremely limited. In the recent years, economic growth and migrants remittances have reduced the level of poverty and brought about substantial improvement in the indicators of human development. Nepal has been, for about a decade, a fragile state marred by civil conflict and political instability. Unfortunately, the open political conflict initiated in 1996 has escalated for about a decade and stopped the country’s progress, and economic performance has declined in recent years. The recently signed (November 2006) comprehensive peace agreement between the government and the conflicting parities has formally ended the decade-long armed insurgency.

The governance system in Nepal includes a central government containing a Council of Ministers at the top and a downward link of line ministries and departments extending their activities outwards to the regions, districts, municipalities and villages. Administratively the country is divided into 5 development regions, 75 district development committees (DDC[12]), 58 municipalities and 3,915 village development committees (VDC[13]). The DDC, municipalities and VDC are the local level government bodies that are responsible for implementation of all kinds of development activities in the respective district, municipal and village development territories (Central Bureau of Statistics, Nepal, 2004).

Out of 75 districts, 57 districts are located in the hill and mountain areas in the north and the other 18 districts are located in the plain areas in the south. Out of 75 administrative districts, 15 district headquarters located in the hill and mountain do not have access to road transport services (Road Statistics, Department of Roads, Nepal, 2005). In the southern Terai areas (approximately 15 percent of the country's area) the situation of development of transportation infrastructure is somewhat different as they have relatively better accessibility compared to the northern hills and mountains (Howe and Richards, 1984). However, they also lack all-weather roads, bridges on river crossings and reliable public transport services. Nepal's economic and social development is closely linked to its geography and accessibility conditions.

3.1.2 Classification of Rural Transport Linkages in Nepal

Nepal Rural Road Standard (1999) provides the classification and other general standards for Rural Transport Networks. All rural transport linkages in Nepal are classified into five classes.

These are:

a. Rural Road Class 'A' - District road
b. Rural Road Class 'B' - Village road
c. Rural Road Class 'C' - Main trail
d. Rural Road Class 'D' - Local/village trail
e. Rural Road Class 'E' - Rope way

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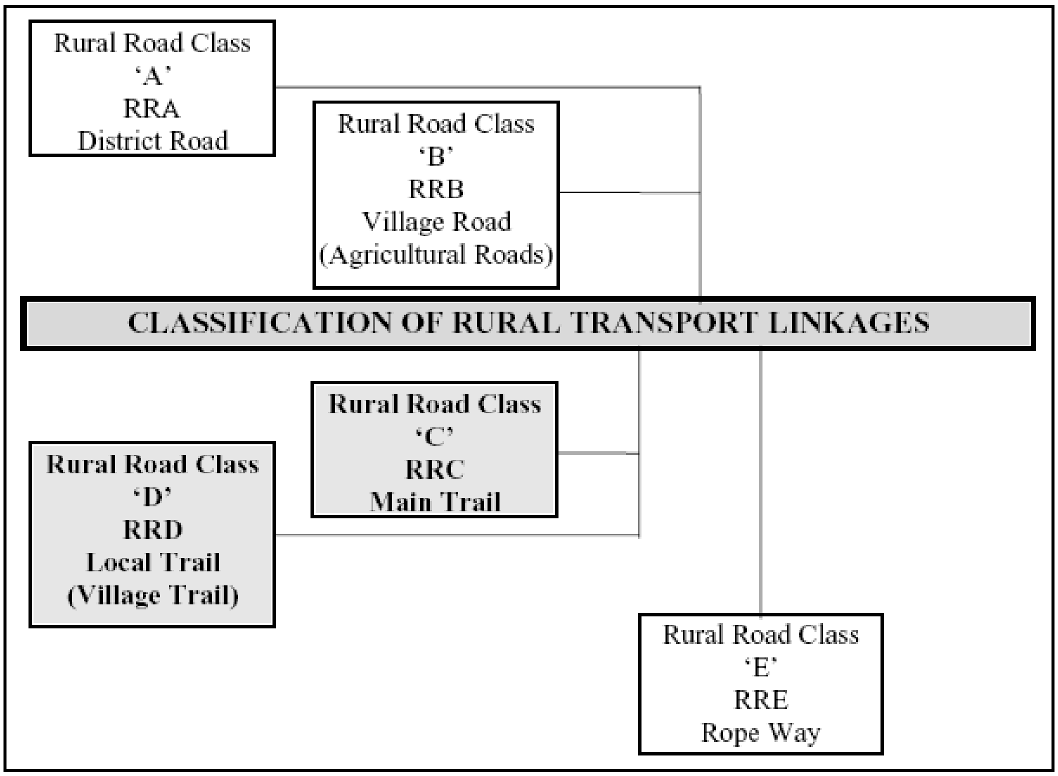
[12] District Development Committee: Constituted as an executive body of the District Council in the district development area.

[13] Village Development Committee: Constituted as an executive body of the Village Council in the village development area.

The classification of rural transport linkages (Figure 3-3) is based on the function of linkage, traffic types and topography of the terrain. These classes are generally grouped into three categories: roads, trails and ropeways.

Figure 3-3: Classification of rural transport linkages in Nepal



Source: Adapted from the Ministry of Local Development, Nepal, 1999.

3.1.3 Rural Bridge Types, their Applications and Construction Costs

The rural bridges in Nepal are generally classified into two types: pedestrian trail bridges and road bridges. Their applications, type of traffic and per meter construction cost are summarized in Table 3.3. The bridges "Type-A" are especially for pedestrian and animal traffic, and are built for crossing rivers and streams along pedestrian trails. The bridges "Type-B" are especially for motor vehicles, and are built over rivers and streams along the rural roads. The focus of the thesis will be on the pedestrian trail bridges (Bridge Type-A).

Table 3.3: Types, applications and estimated construction cost of rural bridges in Nepal

Bridge Type	Crossing Details[14]	Application	Type of Traffic	Per meter Construction Cost [15] (estimated) in CAD $	Nepalese Rupee
A. Pedestrian trail bridges					
Steel truss bridge	Main or local trail (Rural road class 'C', 'D')	Hills or terai Span < 32 m	Pedestrians, Animals	305	20,000
Short span trail bridge	Main or local trail (Rural road class 'C', 'D')	Hills Span ≤ 120 m	Pedestrians, Animals	185 275	12,000 Suspended 18,000 Suspension
Long span trail bridge	Main trail (Rural road class 'C')	Hills or terai Span > 120 m	Pedestrians, Animals	305 455	20,000 Suspended 30,000 Suspension
B. Road bridges					
Modular steel bridge	Rural Road class 'A', 'B'	Terai Span determined by topography and hydrology	One way traffic Trucks < 15 tons, Pedestrians, Animals	3,030	200,000
Motorable suspension bridge	Rural road class 'A', 'B'	Hills Span < 100 m	One way traffic Trucks < 15 tons, Pedestrians, Animals	3,030	200,000
Modified steel Truss bridge	Rural road class 'A', 'B'	Hills Span between 24 and 72 m	One way traffic Trucks<15 tons, Pedestrians, Animals	4,545	300,000
Reinforced cement concrete box bridge	Rural road class 'A', 'B'	Hills or terai Span determined by topography and hydrology	One way traffic Trucks < 15 tons, Pedestrians, Animals	2,655	175,000

Source: Adapted from Trail Bridge Section, Nepal, 2005.

[14] The Ministry of Local Development, Department of Local Infrastructure Development and Agricultural Roads has classified Rural Roads in five types. Class A-District roads, Class B-Village roads, Class C-Main trails, Class D - Local trails and Class E –Rope ways (Section 1.4).

[15] CAD $1 = Nepalese Rupee 66 (July 2006)

3.1.4 Development of Trail Bridge Building Practices in Nepal

Trail bridge planning is challenging because it requires an understanding of multidisciplinary fields such as physics, architecture, engineering and social sciences (Ryan, 1993). At the same time, trail-bridges can be some of the most interesting features of a multi-use trail especially if they offer compelling views and ease the river crossing hazard (Ryan, 1993). The function of a trail-bridge is primarily to provide trail users with safe passage over natural features such as rivers, gorges and also some built features such as roadways and canals (Ryan, 1993).

The focus of the thesis will be on planning the location of the pedestrian trail-cable suspension bridges (Figure 2-1, Figure 2-3) over river crossings in the context of Nepal. Pedestrian trail-suspension bridge building has a long history and strong tradition in the hills and mountains of Nepal. For centuries narrow gorges have been crossed either with simple logs or improvised bamboo crossings or skillfully constructed cantilever bridges that look artistic but can pose a crossing hazard. Iron chain bridges, dugout ferry-boats, plant fibre or simple but dangerous wire rope crossings (Figure 3-4) have been built for wider rivers. Many tragic accidents occur in which villagers, often children, are swept away in gushing rivers (Devkota et al., 2004). These historical but dangerous trail bridges and new river crossings that are identified or developed in the course of development and expansion of transport infrastructure and services are being realized in order to make road and trail networks functional. A sturdy small trail bridge not only helps to prevent accidents but also promotes local trade and provides access for the people to social service centers.

Figure 3-4: Traditional trail-bridges and river crossing means; a) An iron chain bridge, b) A premitive and risky bamboo bridge, c) A premitive and risky cable crossing, and d) A traditional dugout ferry-boat crossing

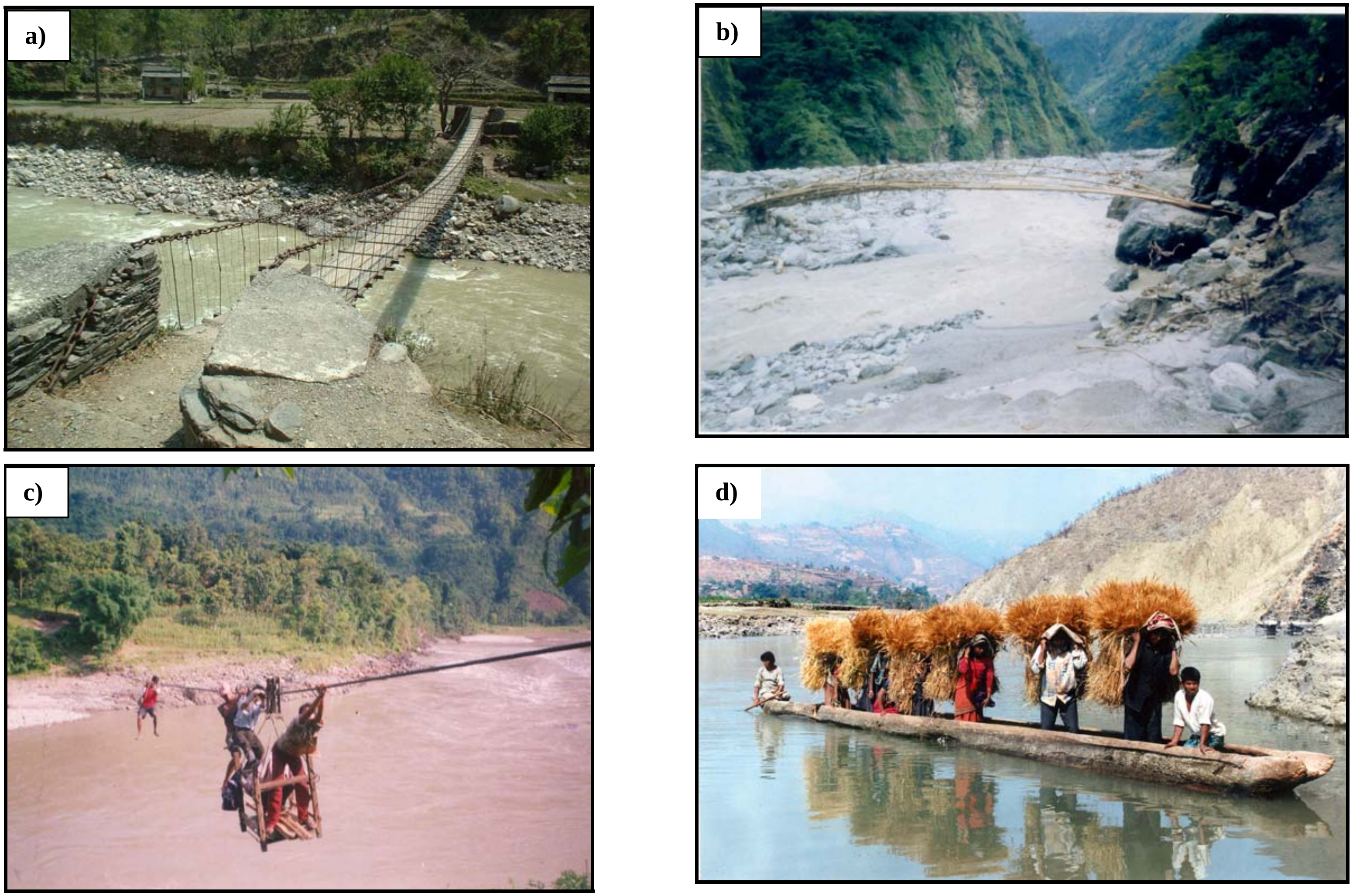


Photo source: Trail Bridge Section, Nepal, 2005.

In the beginning of the 20th century, the Government of Nepal was actively involved in building trail bridges at strategic locations along major trade routes. These bridges were manufactured in Scotland, dispatched in parcels to Nepal and subsequently erected at the site (Trail Bridge Section, 2005). The large-scale construction of such bridges only became a development priority for Nepal at the beginning of the 1960's. The government set up a Suspension Bridge Division in 1964 as a commitment to providing safe and durable trail bridges for providing basic access to the rural areas. The main organizations that have been working to improve trail bridge building technology since the beginning of the 1960's are the government's Suspension Bridge Division, the Swiss Agency for Development and Cooperation and Helvetas[16], and the Swiss Association for International Cooperation. Building on the success of the past experiences and advances in engineering technology and practices; trail bridge planning, design and construction processes have been standardized and are

Figure 3-5: Modern engineered trail bridges for providing safe and basic access needs for rural people of Nepal

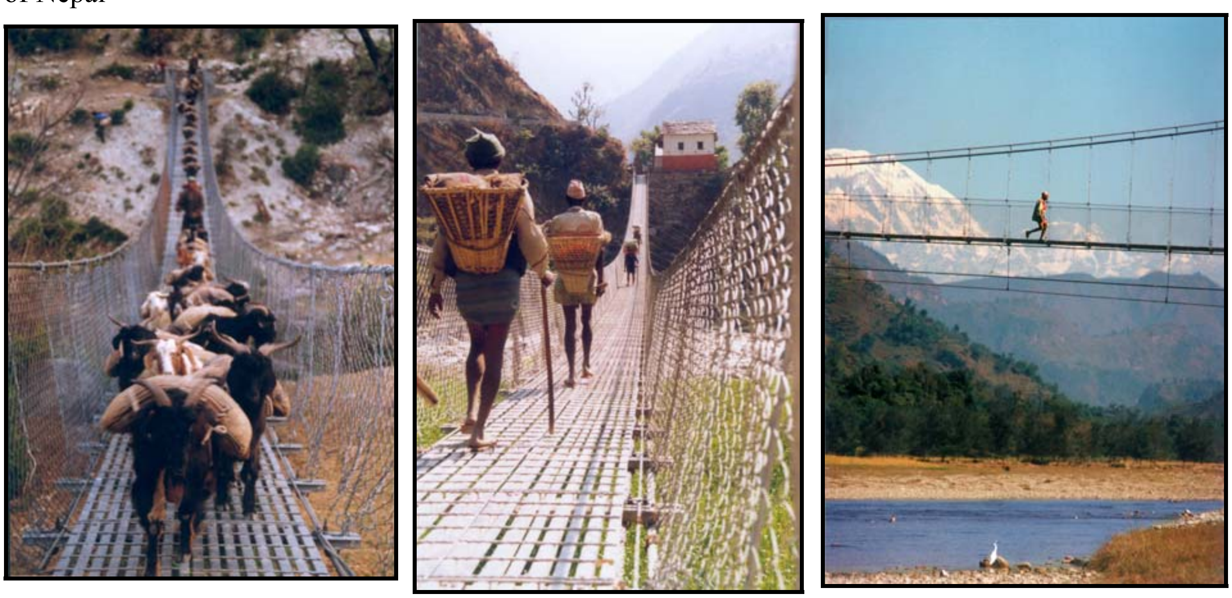


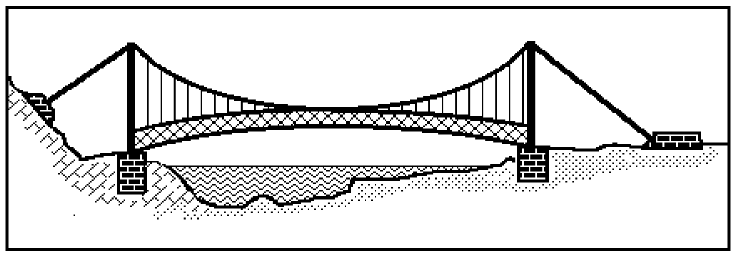
Photo source: Trail Bridge Section, Nepal, 2005.

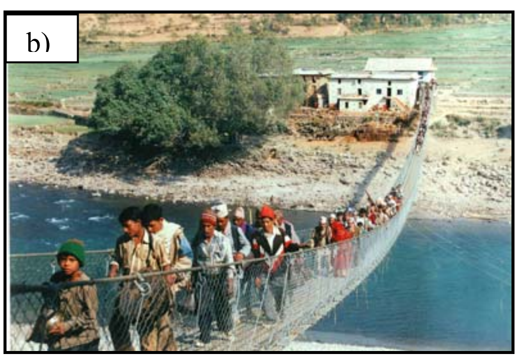
[16] Helvetas: Swiss Association for International Cooperation - A Swiss Non-Governmental Development Organization with programs in 22 developing countries in Asia, Africa and Latin America. Its program focus is in four working areas. These are: Infrastructure in Rural Areas, Sustainable Management of Natural Resources, Education and Culture, and Civil Society and the State (http://www.helvetas.ch/).

being followed by the entire bridge sector program in Nepal. Also, there have been innovations in engineering technology, design, planning and construction practices have been evolved significantly in the course of trail bridge building practices over the years (Figure 3-5).

There are three types of standard pedestrian trail bridges currently being constructed in Nepal. These are: a) suspension type, b) suspended type, and c) steel truss type. Two of them: a) and b) are most widely used which are illustrated in Figure 3-6 (Poudel et al., 2003).

Figure 3-6: Pedestrian trail bridge types a) Suspension type, and b) Suspended type





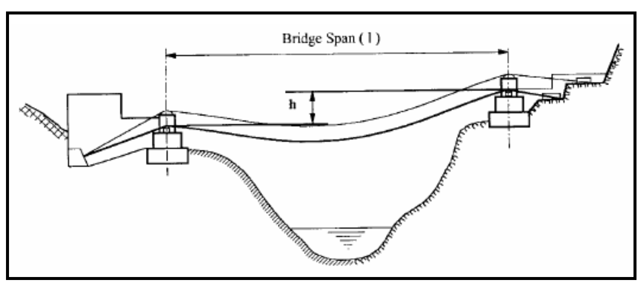


Photo source: Trail Bridge Section, Nepal, 2005.

The selection decision of trail bridge type primarily depends on the prevailing topography of the potential trail-bridge site location. The suspended type bridge is selected when the bridge foundations can be placed at a sufficiently high positions providing required freed board from the highest flood level. These trail-bridges can span upto 350 m. By contrast, the suspension type of trail bridge is selected when the topography of the potential trail bridge site is comparatively flat and a suspended bridge is not be feasible. The suspension type trail bridge can span upto 280 m. Steel truss bridges are suitable at locations with high river banks and narrow river width spanning less than 32 m. Most of the activities at the planning (pre-construction), construction and post-construction stages of all types of trail bridge projects are similar. However, in technical aspects, they have different geometric parameters and configurations, and they also differ in some structural components.

3.1.5 Case Study District

Okhaldhunga district was selected for the specific case study representing a typical hill and mountain district in the eastern region of the country. Its geography, demography, rural transport systems and social services are summarized in the following sub-sections.

3.1.5.1 Geography and Demography

Okhaldhunga district is one of the 75 administrative districts[17] of the country, which is surrounded by major rivers to the east, west and south, and a high mountain ridge to the north. It is situated in the core of eastern Nepal between 27° 8’ and 27° 33’ north latitude and 86° 10’ to 86° 42’ east longitude. It covers an area of 1,088 sq km and has a population of 141,279 (2001 population census). The population density of the district is 130 inhabitants per sq. km (Central Bureau of Statistics, Nepal, 2004). For the district as a whole, land use is predominantly agricultural, as is the economy. This district represents typical rural conditions in Nepal. Table 3.4 provides some location information and a demographic profile of the district.

[17] There are a total of 75 administrative districts in Nepal.

Table 3.4**:** Okhaldhunga district location and demographic profile

Latitude [north]	27° 8’ to 27° 33’
Longitude [east]	86° 10’ to 86° 42’
Area [sq. km]	1,088
Total population (2001)	141,289
Number of households	26,706
Average household size	5
Population growth rate [%]	1.3
Population density [inhabitants/km^2]	130

Data source: Central Bureau of Statistics, Nepal, 2004.

Due to the difference of altitude, the climate varies from sub-tropical to cold temperate climate. There is sub-tropical climate in the southern part of the district and in the major river valleys. The hill areas and the northern part of the district have cold temperate climate with light snow fall during the winter season. The average temperature of the district is 1.4° Centigrade in the winter season and 24.3° Centigrade in the summer season. The average annual rainfall is 1,650 millimeter.

The district is administratively divided into two electoral constituencies and 54 village development committees (Ministry of Local Development, Nepal, 2005; Okhaldhunga District Transport Master Plan, 2002). Settlement villages and service centers are spread across the district. Population in the settlement villages ranges from 1,275 to 4,080 people and their areas range from 6.21 sq km to 57.29 sq km. The density of population in the settlement villages ranges from 38 to 316 people per sq km.

3.1.5.2 Rural Transport, Settlement Villages and Social Services

The road transport system in the district is in the preliminary stage of development. A feeder road, of approximately 90 km, is under construction which passes from southern parts to northern parts through the district headquarters. It connects the district to the market centers at the south and the

Terai plain. The nearest all-weather road head node is located at least two to two and half days walking distance from the district headquarters. As a result, the trail-based transport system, especially pedestrian foot trails and trail bridges, plays an important role in providing basic transport services for the mobility of the people within the district and also connecting with the neighboring districts. The socioeconomic activities are largely dependent on trail-based transport and communication systems. There is one fair-weather airport in the district which connects the district headquarters by air services to the national capital, Kathmandu and the eastern Terai business center Biratnagar. However, the air services are not affordable by the rural communities for their day-to-day travel and also the supply is very low and irregular.

A fairly dense network of approximately 1,100 km of foot-trails is distributed across the district, east- west and north-south. These trails connect settlement villages and social service centers within the district and also extended to the neighboring districts. There are three major rivers that flow along the border of the district. Additionally, there are numerous other rivers that flow in the watershed areas of these major rivers. The foot trails and rivers criss-cross at numerous locations which create difficulties and barrier (impedance) for movement of people and goods across and out of the district. These river crossing locations are of special interest for the present research study.

At present (2005), there are a total of 61 trail bridges along the foot trails at river crossing locations (Nepal Trail Bridge Record, 2005). The number of trail bridges is fairly low as compared to the number of river crossing locations that may potentially require trail bridges. The required number of additional new trail bridges has been estimated at 136. The lack of trail bridges at some river crossing locations creates difficulties and in some instances prevents the people from accessing the various social services (listed below) available in the district.

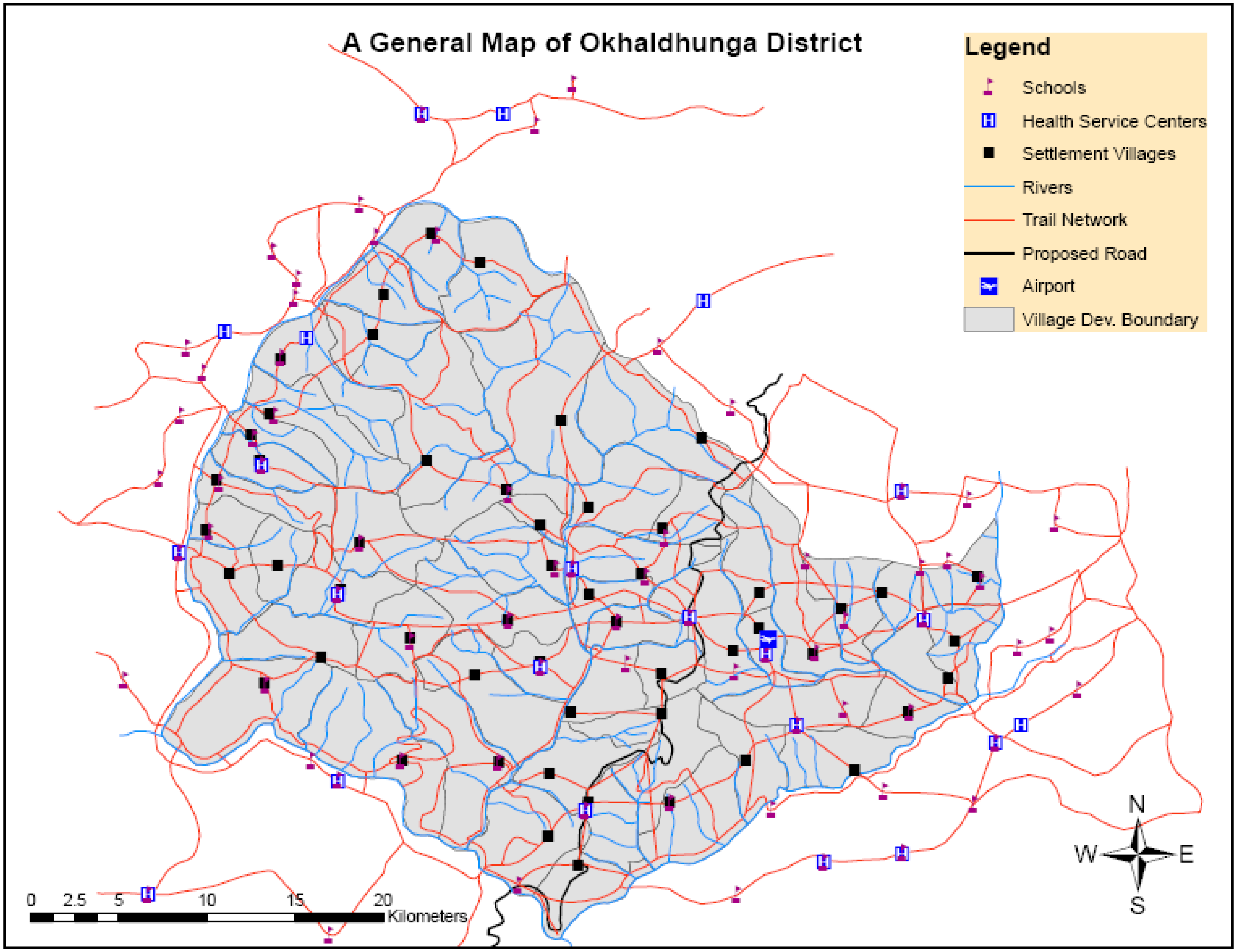
a) Health (ayurvedic clinic[18], health post, health center, hospital)
b) Education (lower secondary school, secondary school, campus[19])
c) Communication (post office, wireless station)
d) Transport (road head node, airport)
e) Electricity (power supply)

[18] Ayurvedic clinic: Herbal medicine clinic
[19] Campus: Campus represents higher secondary school with grades 11 and 12.

f) Trade (market centers, weekly markets)
g) Industry (crafts, small and large scale industry)
h) Bank (commercial bank, agriculture development bank, farmers' development bank)
i) Agriculture (factory, mill, agriculture development project, irrigation project)
j) Police service (police post)
k) Tourism (lodges, hotels, parks)
l) Religious sanctuary (temples, etc.)

Figure 3-7 provides an overview of spatial distribution of service centers (only health service centers and schools are shown on the map), trail network, river system and settlement villages.

Figure 3-7: A general map of the district with spatial distribution of service centers, trail network, river system and settlement villages



3.2 Data Sources and Acquisition

A variety of data were collected in various formats from different sources for analysis. Figure 3-8 summarizes data types and sources. Figure 3-9 and Figure 3-10 illustrate some sample views of the spatial and attribute data sets. An overview of data about the settlement villages in the district is provided in the Appendix D.

Figure 3-8: Types and sources of data

Type of Datasets	Data Source
Spatial data	
District Transport Infrastructure Maps in prints (paper maps), 1: 125,000	Trail Bridge Section, Nepal, 2005.
District Transport Infrastructure Maps in digital data (digital data in Macromedia Freehand file format)	Trail Bridge Section, Nepal, 2005. Available at http://www.nepaltrailbridges.org/
District Central Service Map in prints (paper map), 1: 125,000	Trail Bridge Section, Nepal.
Attribute Data	
Trail bridge attribute databases in MS Access system	Trail Bridge Section, Nepal, 2005.
Trail bridge attribute databases in FoxPro database system	Trail Bridge Section, Nepal, 2005.
A listing of existing trail bridges in the districts published in a form of the "Nepal Trail Bridge Record", 2005	Trail Bridge Section, Nepal, 2005.
Data on population and demography, 2001	Population Census 2001, Central Bureau of Statistics, Nepal.
Information on social services (health services, school, post office, bank, transport, industry, etc.)	Derived from the Central Service Map

3.2.1 Spatial data

The recently published (2005) paper maps were used as reference spatial data. These maps, trail bridge attribute data and other demographic and social information were acquired separately as these datasets were not integrated in a single database system. Paper maps of 1: 125,000 were used as base maps for creation of spatial digital data by digitizing. These paper maps provide location of village settlements, administrative boundaries, trail network, existing trail bridges, river system, proposed roads, location and functional attributes of social services.

3.2.2 Attribute data

The trail bridge attribute databases were developed and maintained by the Trail Bridge Section of Nepal separately independent from the map database during the period 1990-2005 in a variety of formats: dBASE, FoxPro and MS Access database systems. As such some editing and export to a common Access database was necessary in order to integrate them with the ArcGIS map features. The demographic and social characteristics of settlement villages were extracted from the 2001 census data (Central Bureau of Statistics, Nepal, 2004) and the paper maps.

Figure 3-9: A general view of the District Transport Infrastructure Map

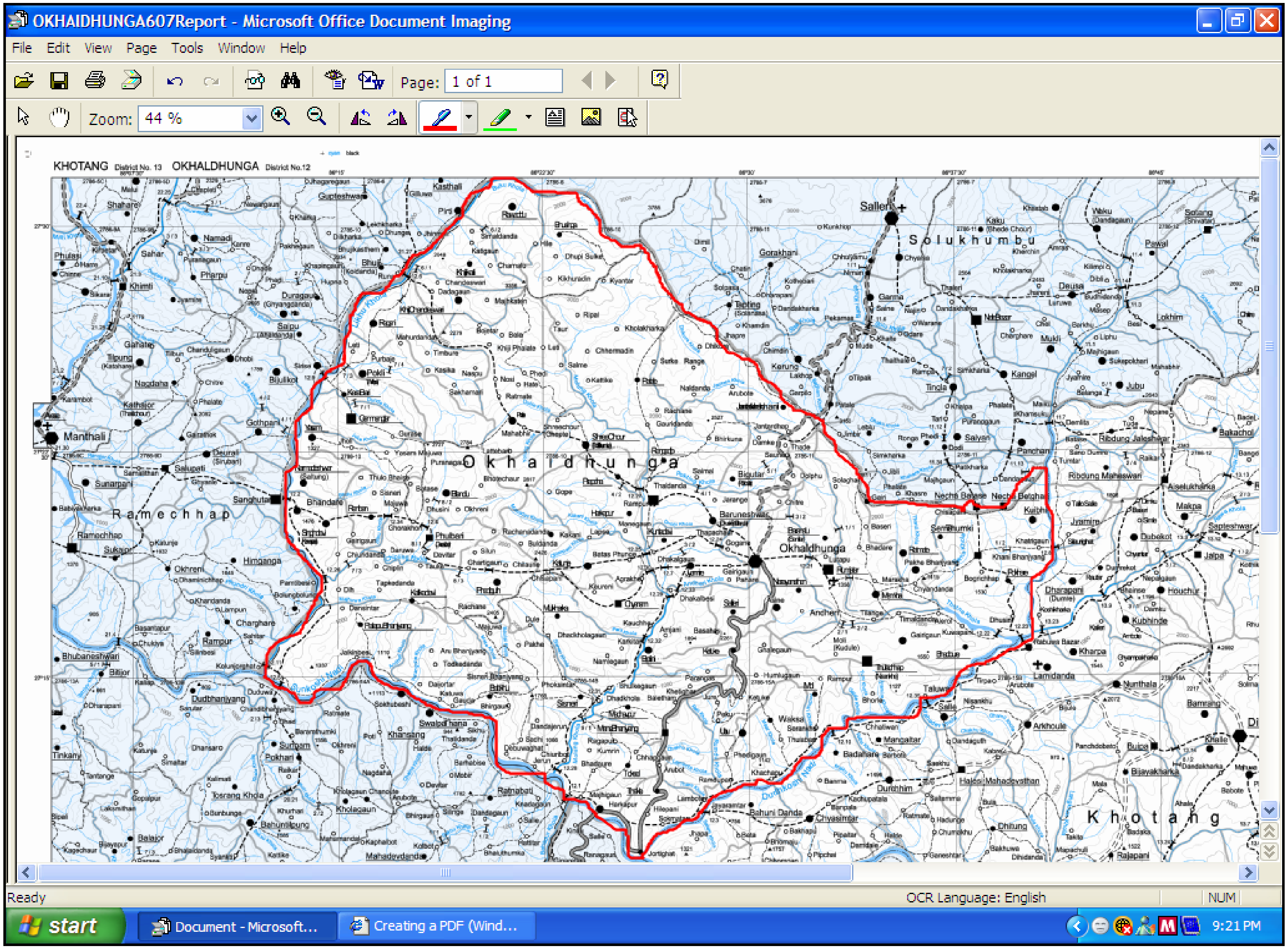
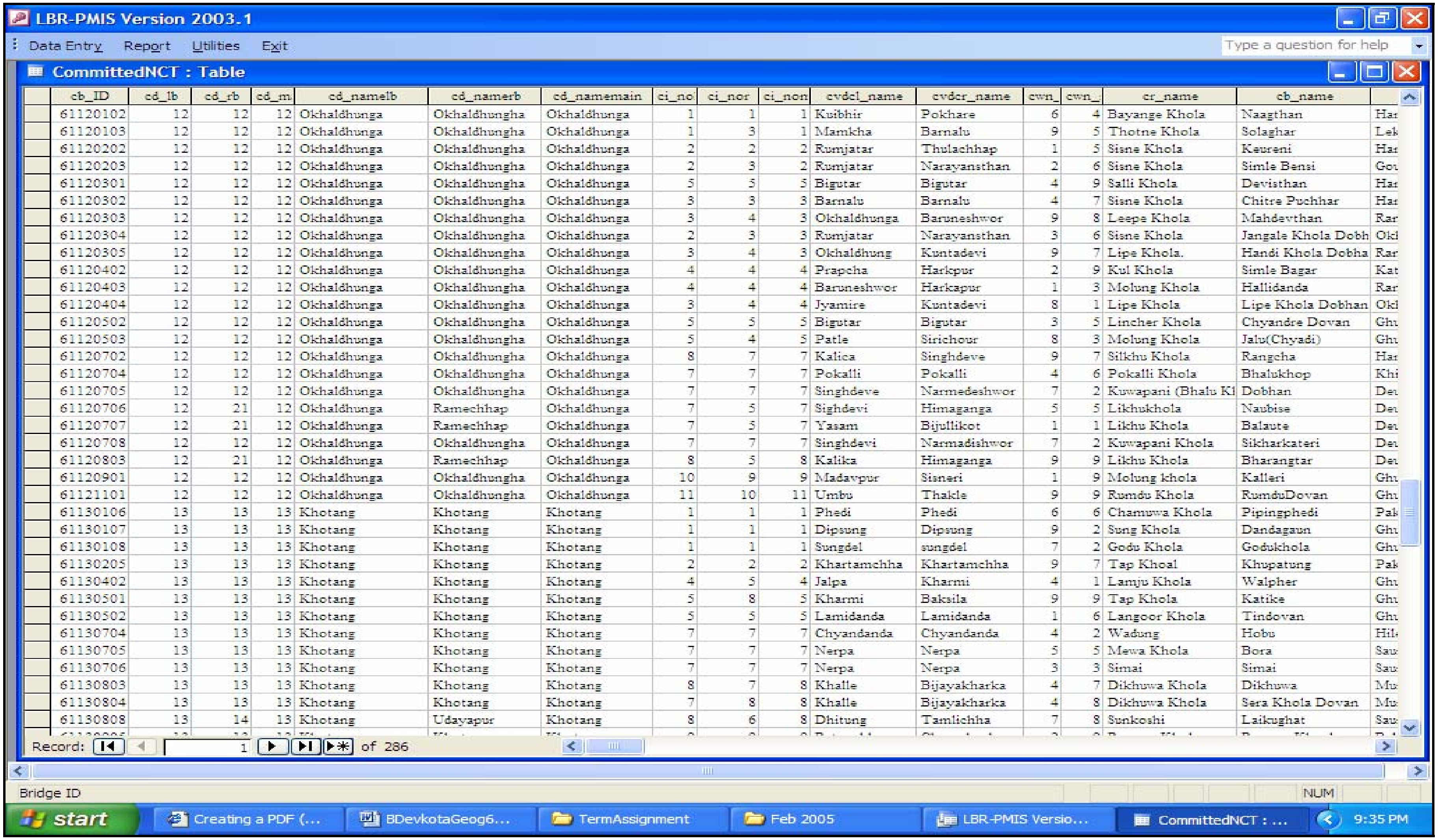


Figure 3-10: A view of the attribute data of the trail bridges in the MS Access database system



cb_ID	cd_lb	cd_rb	cd_m	cd_namelb	cd_namerb	cd_namemain	ci_no	ci_nor	ci_non	cvdcl_name	cvdcr_name	cwn_	cwn_	cr_name	cb_name	
61120102	12	12	12	Okhaldhunga	Okhaldhungha	Okhaldhunga	1	1	1	Kuibhir	Pokhare	6	4	Bayange Khola	Naagthan	Har
61120103	12	12	12	Okhaldhunga	Okhaldhungha	Okhaldhunga	1	3	1	Mamkha	Barnalu	9	5	Thotne Khola	Solaghar	Lek
61120202	12	12	12	Okhaldhunga	Okhaldhungha	Okhaldhunga	2	2	2	Rumjatar	Thulachhap	1	5	Sisne Khola	Keureni	Har
61120203	12	12	12	Okhaldhunga	Okhaldhungha	Okhaldhunga	2	3	2	Rumjatar	Narayansthan	2	6	Sisne Khola	Simle Bensi	Gou
61120301	12	12	12	Okhaldhunga	Okhaldhungha	Okhaldhunga	5	5	5	Bigutar	Bigutar	4	9	Salli Khola	Devisthan	Har
61120302	12	12	12	Okhaldhunga	Okhaldhungha	Okhaldhunga	3	3	3	Barnalu	Barnalu	4	7	Sisne Khola	Chitre Puchhar	Har
61120303	12	12	12	Okhaldhunga	Okhaldhungha	Okhaldhunga	3	4	3	Okhaldhunga	Baruneshwor	9	8	Leepe Khola	Mahdevthan	Rar
61120304	12	12	12	Okhaldhunga	Okhaldhungha	Okhaldhunga	2	3	3	Rumjatar	Narayansthan	3	6	Sisne Khola	Jangale Khola Dobh	Okl
61120305	12	12	12	Okhaldhunga	Okhaldhungha	Okhaldhunga	3	4	3	Okhaldhung	Kuntadevi	9	7	Lipe Khola.	Handi Khola Dobha	Rar
61120402	12	12	12	Okhaldhunga	Okhaldhungha	Okhaldhunga	4	4	4	Prapcha	Harkpur	2	9	Kul Khola	Simle Bagar	Kat
61120403	12	12	12	Okhaldhunga	Okhaldhungha	Okhaldhunga	4	4	4	Baruneshwor	Harkapur	1	3	Molung Khola	Hallidanda	Rar
61120404	12	12	12	Okhaldhunga	Okhaldhungha	Okhaldhunga	3	4	4	Jyamire	Kuntadevi	8	1	Lipe Khola	Lipe Khola Dobhan	Okl
61120502	12	12	12	Okhaldhunga	Okhaldhungha	Okhaldhunga	5	5	5	Bigutar	Bigutar	3	5	Lincher Khola	Chyandre Dovan	Ghu
61120503	12	12	12	Okhaldhunga	Okhaldhungha	Okhaldhunga	5	4	5	Patle	Sirichour	8	3	Molung Khola	Jalu(Chyadi)	Ghu
61120702	12	12	12	Okhaldhunga	Okhaldhungha	Okhaldhunga	8	7	7	Kalica	Singhdeve	9	7	Silkhu Khola	Rangcha	Har
61120704	12	12	12	Okhaldhunga	Okhaldhungha	Okhaldhunga	7	7	7	Pokalli	Pokalli	4	6	Pokalli Khola	Bhalukhop	Khi
61120705	12	12	12	Okhaldhunga	Okhaldhungha	Okhaldhunga	7	7	7	Singhdeve	Narmedeshwor	7	2	Kuwapani (Bhalu Kl	Dobhan	Deu
61120706	12	21	12	Okhaldhunga	Ramechhap	Okhaldhunga	7	5	7	Sighdevi	Himaganga	5	5	Likhukhola	Naubise	Deu
61120707	12	21	12	Okhaldhunga	Ramechhap	Okhaldhunga	7	5	7	Yasam	Bijullikot	1	1	Likhu Khola	Balaute	Deu
61120708	12	12	12	Okhaldhunga	Okhaldhungha	Okhaldhunga	7	7	7	Singhdevi	Narmadishwor	7	2	Kuwapani Khola	Sikharkateri	Deu
61120803	12	21	12	Okhaldhunga	Ramechhap	Okhaldhunga	8	5	8	Kalika	Himaganga	9	9	Likhu Khola	Bharangtar	Deu
61120901	12	12	12	Okhaldhunga	Okhaldhungha	Okhaldhunga	10	9	9	Madavpur	Sisneri	1	9	Molung khola	Kalleri	Ghu
61121101	12	12	12	Okhaldhunga	Okhaldhungha	Okhaldhunga	11	10	11	Umbu	Thakle	9	9	Rumdu Khola	RumduDovan	Ghu
61130106	13	13	13	Khotang	Khotang	Khotang	1	1	1	Phedi	Phedi	6	6	Chamuwa Khola	Pipingphedi	Pak
61130107	13	13	13	Khotang	Khotang	Khotang	1	1	1	Dipsung	Dipsung	9	2	Sung Khola	Dandagaun	Ghu
61130108	13	13	13	Khotang	Khotang	Khotang	1	1	1	Sungdel	sungdel	7	2	Godu Khola	Godukhola	Ghu
61130205	13	13	13	Khotang	Khotang	Khotang	2	2	2	Khartamchha	Khartamchha	9	7	Tap Khoal	Khupatung	Pak
61130402	13	13	13	Khotang	Khotang	Khotang	4	5	4	Jalpa	Kharmi	4	1	Lamju Khola	Walpher	Ghu
61130501	13	13	13	Khotang	Khotang	Khotang	5	8	5	Kharmi	Baksila	9	9	Tap Khola	Katike	Ghu
61130502	13	13	13	Khotang	Khotang	Khotang	5	5	5	Lamidanda	Lamidanda	1	6	Langoor Khola	Tindovan	Ghu
61130704	13	13	13	Khotang	Khotang	Khotang	7	7	7	Chyandanda	Chyandanda	4	2	Wadung	Hobu	Hil
61130705	13	13	13	Khotang	Khotang	Khotang	7	7	7	Nerpa	Nerpa	5	5	Mewa Khola	Bora	Sau
61130706	13	13	13	Khotang	Khotang	Khotang	7	7	7	Nerpa	Nerpa	3	3	Simai	Simai	Sau
61130803	13	13	13	Khotang	Khotang	Khotang	8	7	8	Khalle	Bijayakharka	4	7	Dikhuwa Khola	Dikhuwa	Mu
61130804	13	13	13	Khotang	Khotang	Khotang	7	8	8	Khalle	Bijayakharka	4	8	Dikhuwa Khola	Sera Khola Dovan	Mu
61130808	13	14	13	Khotang	Udayapur	Khotang	8	6	8	Dhitung	Tamlichha	7	8	Sunkoshi	Laikughat	Sau

Data source for Figure 3-9and Figure 3-10: Trail Bridge Section, Nepal, 2005.

3.3 Methods

The methodology utilizes a GIS to prepare and analyze the spatial and attribute database of the district. ESRI ArcGIS 9, ArcGIS Arc 9.1, MS Access, FoxPro database applications were used to create, acquire, edit and manage spatial and attribute data, and for spatial analysis (Table 3.5).

Table 3.5**:** Computer software applications used for data acquisition and analysis

GIS software	**Analytic components, functions**
ESRI ArcGIS 9 ArcCatalog, ArcMap, ArcToolbox	Spatial data creation, editing, conversion, data integration, visualization, Spatial analysis, Network analysis
ESRI ArcGIS ArcInfo Workstation, Arc	Spatial interaction modeling Accessibility modeling
Other applications	
Adobe Illustrator	Data transfer
Macromedia Freehand	Map creation, manipulation, data transfer
MS Access Database	Database management, data edit, data transfer
FoxPro Database	Database management, data edit, data transfer

For organizational purposes, the research procedure was divided into four main stages:

a) the creation of a conventional base map of the district with information mainly on settlements villages with their population and boundaries, road and trail network, existing trail bridges, river system, social service center locations and river crossing locations,

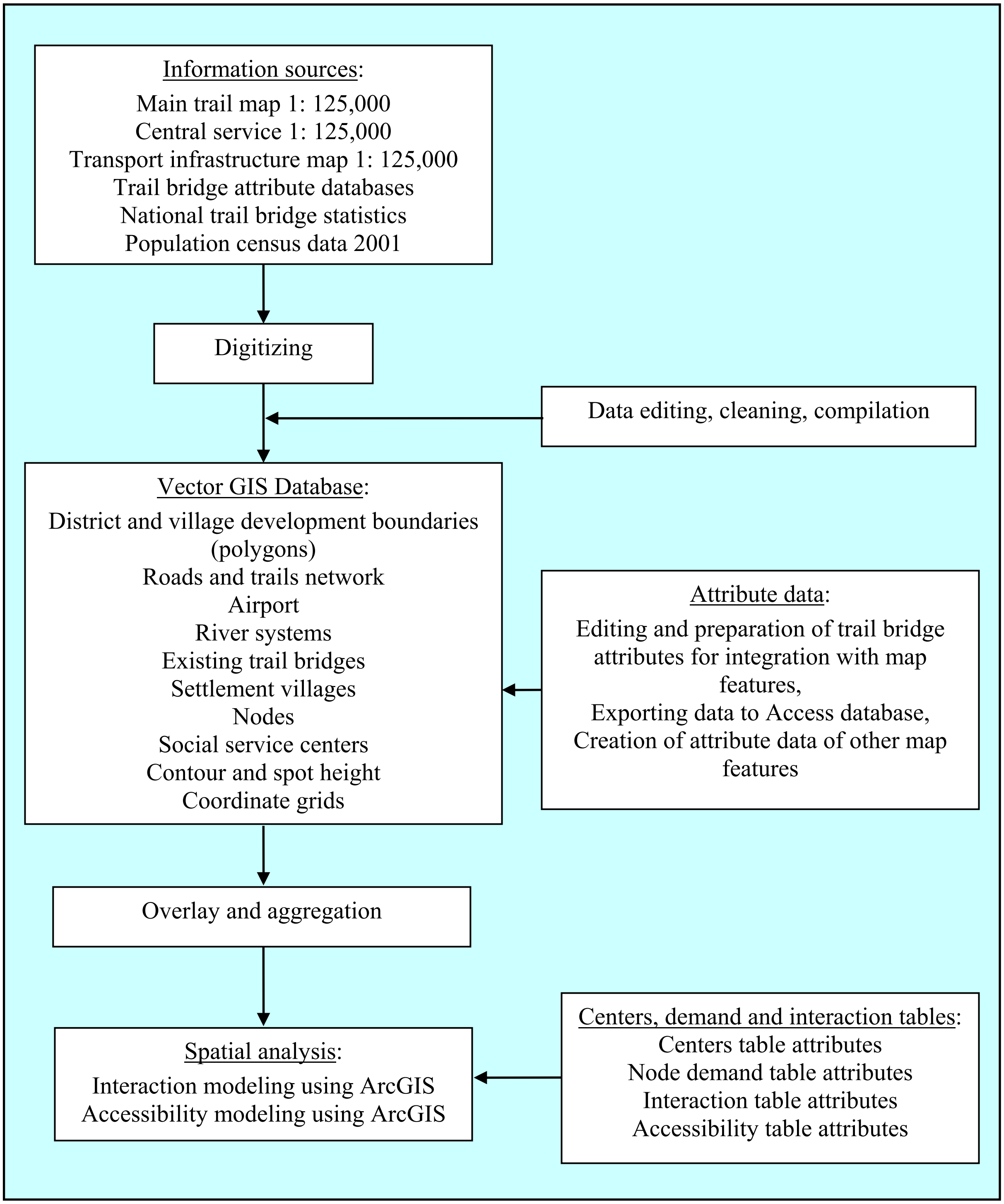
b) the compilation of the GIS database and the integration of trail bridge attribute data with the map features,

c) the spatial interaction and accessibility modeling using ArcGIS,

d) the optimization of additional new trail bridges.

Figure 3-11 provides an outline of major steps involved in each of these stages which include data acquisition, compilation, digitization, processing, integration, overlaying and spatial analysis.

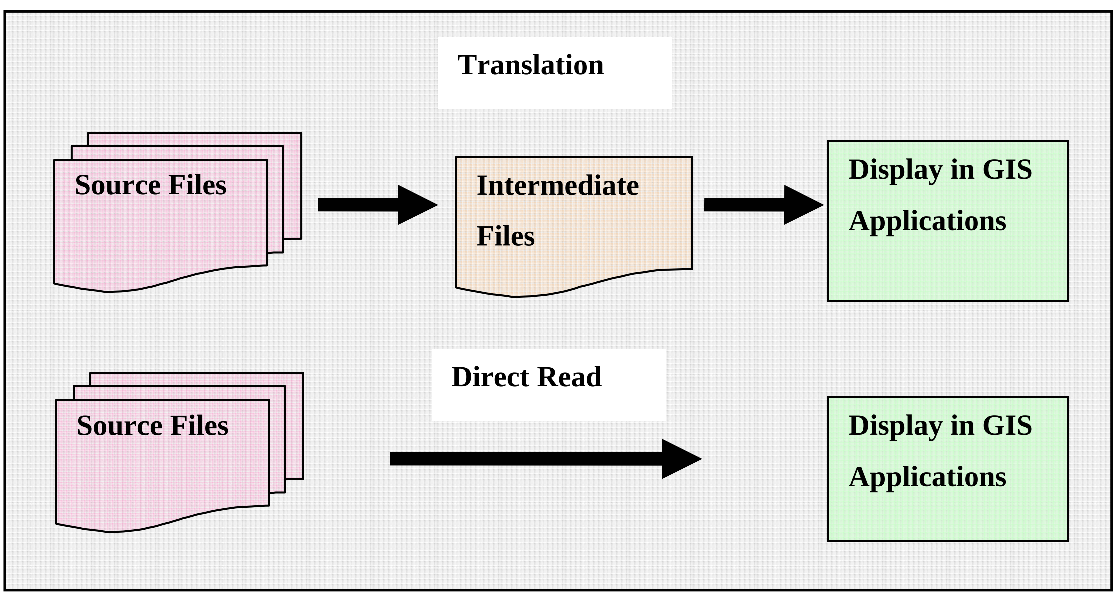
Figure 3-11: Compilation and analysis of GIS database



3.3.1 Data Transfer, Creation and Integration

GIS usually rely on data collected for some other purposes (Martin, 1991). One potential problem associated with data obtained from external sources is that they can be encoded in many different formats to meet the requirements of their own applications and circumstances of different organizations (Longley et al., 2005). There are many different geographic data formats because no single format is appropriate for all tasks. Input of these data in many cases involves importing of records from databases existing within other systems (Martin, 1991). Data can be transferred between systems by direct read into memory or via an intermediate file format (Figure 3-12). The most efficient way to translate data between systems is usually via a common intermediate file format (Longley et al., 2005). However, in order to create intermediate files it might be necessary to use some other software applications that can bridge the gap between GIS data and the original data by preparing common files (intermediate files) from the original data sets.

Figure 3-12: Methods of data access by translation and direct read



Source: Adapted from Longley et al., 2005.

The methodology for data transfer, data creation and analysis was worked out for one representative administrative district (Okhaldhunga district). This approach can be replicated in other administrative districts. In order to transfer the spatial data of the Transport Infrastructure Maps from Macromedia Freehand system into ArcGIS system several attempts were made to create intermediate files*: shape file (*.shp), database file (*.dbf) and index file (*.shx)* with the help of Adobe Illustrator. These include exporting from Macromedia Freehand files to *.eps format and then again exporting to *.dxf or *.dwg files by creating intermediate files. The *.dxf or *.dwg files were added to ArcGIS map document. But the information contained in the original maps was distorted and was not legible for further use. At the moment the MAPublisher applications as envisaged by the Trail Bridge Section, Nepal, who prepared these original maps, for data transfer by creating intermediate files, were not available. Hence, this approach of data transfer for the purpose of the present study was dropped which needs to be explored in future study. Alternatively, the spatial data were created from the paper maps by digitizing.

All spatial data were created from the print maps using table digitizing with ESRI ArcMap. The methods and procedures for table digitizing, as outlined by the Mapping, Analysis & Design (2005) in table digitizing were followed to create a composite thematic base map comprising various map layers. The paper maps were examined and registered with the reference coordinate grids. To capture the features and associated information from the paper maps, separate shapefiles were created. In order for each shapefile to be superimposed correctly as map layer, each must be stored in the same spatial reference (geographic projection and coordinate system). Spatial reference of all the shapefiles were defined in Projected Coordinate System, WGS_1984_UTM_Zone45N, which is the recommended UTM projection for Nepal located between 26° and 31° north latitude and 80° and 87° east longitude. Attributes of the map features were added to their respective attribute data tables except for trail bridges as the attributes of trail bridges were available in separate database files.

The attribute data of the existing trail bridges, which was available in FoxPro and MS Access database systems, were examined in terms of their quality, completeness, format and field properties. The attribute stored in the FoxPro database tables were imported to Access database tables. Then, these database tables were added to the ArcMap document. A common field was added into both attribute tables. The attributes of the trail bridge database table and the map features were integrated (joined) with a common field - bridge id-number (BridgeNumber) that exists in both data sets.

3.3.2 Spatial Interaction and Accessibility

Gravity-based methods were used for modeling the spatial interaction between the population and the social service centers and also for measuring accessibility from settlement village (nodes) to social service centers. ARC/INFO provides two commands, “ACCESSIBILITY” and “INTERACTION” that use gravity-model concepts. ACCESSIBILITY computes how accessible a location is to other locations given the attractiveness of other locations. INTERACTION computes detailed levels of interaction between pairs of origins and destinations taking into account properties of the origin in producing a trip and destination properties of attracting a trip. ArcMap is used to run the analysis and display the results.

Among different types of social services available in the district, health service centers and schools are taken up for modeling interaction and accessibility as these two types of services are considered of primary importance in the rural context of Nepal. A total of 22 health service centers and 72 schools are relevant to Okhaldhunga District including some located in the neighboring districts that are located in the close proximity to the district border. People may have options to travel to any of these service centers inside and out the district. Spatial interaction and accessibility are run separately for health service centers and for schools. The required datasets are summarized in Table 3.6.

Table 3.6**:** GIS data sets for interaction and accessibility analysis

Sn	Datasets	Description
1	VDCBOUNINOUT	Polygon feature class, District boundary polygon shapefile, Settlement village area polygon shapefile with demographic attributes
2	FTRL2C (TRAIL NETWORK ARC)	Trail network arc coverage
3	NODES ON TRAIL NETWORK	Trail network node feature class
4	HELTHSERVICESALL	Health service centers point shapefile with supply attribute
5	EDUCATIONALL	School centers point shapefile with supply attribute
6	TRUNTABLES	Turn table with turn impedance items

Both types of models are based on the same set of 616 nodes. These nodes are the basic unit of analysis in the spatial modeling exercises. Nodes represent the origin and/or destination points for travel. These nodes are computed at the points of intersection of trails, location of service centers, locations of existing trail bridges and intersection of trails and rivers. Out of total 616 nodes, 458 nodes are located within the district boundary and the remaining 158 nodes are located outside the district boundary. Only those nodes within the district boundary will be allocated population attributes. Nodes located outside the district boundary will not create any demand, as the analysis will focus exclusively on trips originating within the Okhaldhunga District.

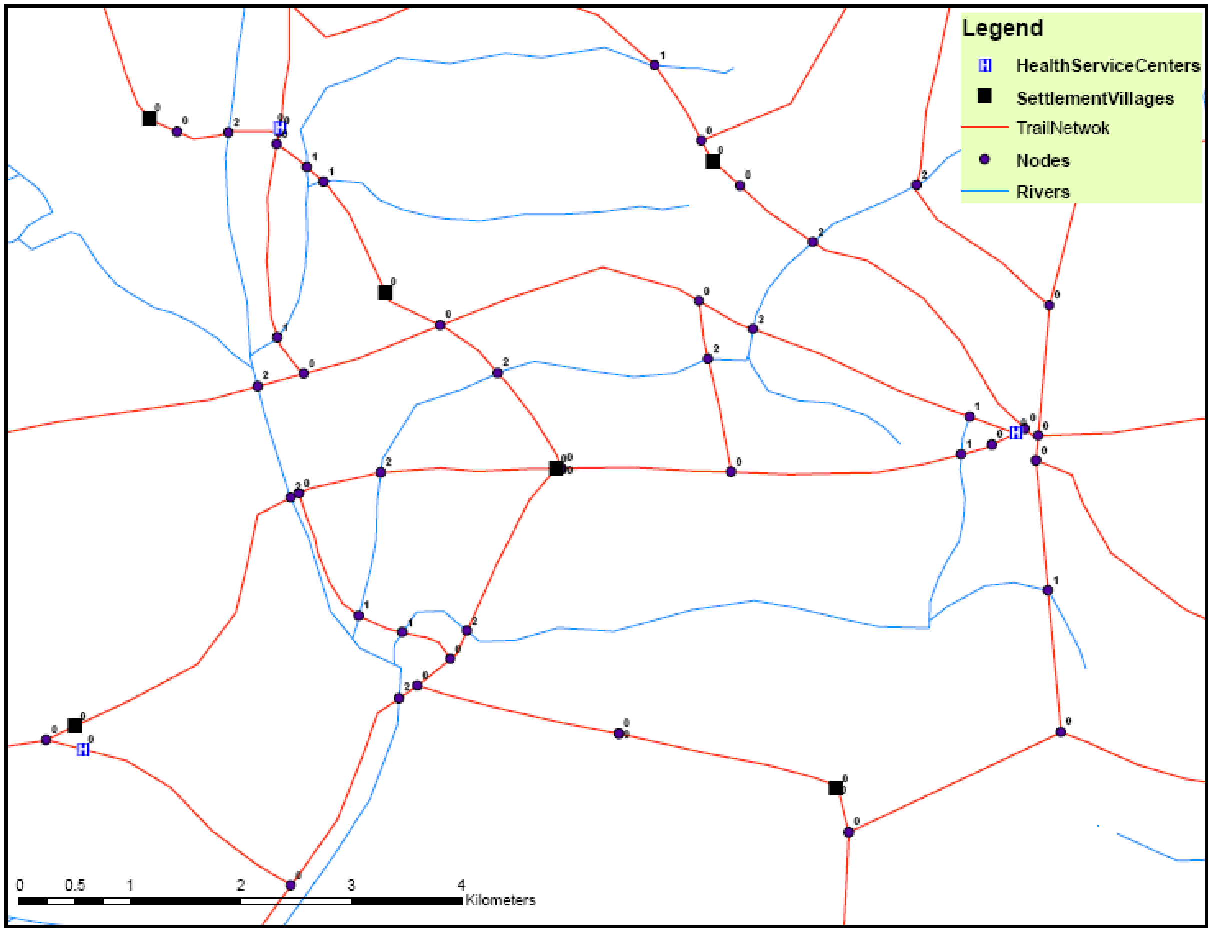
Nodes on the trail networks were categorized into three different types on the basis of their location on the trail network. These are:

node type 1 = nodes at the intersections of trail network and river system without trail bridges (136 nodes; all nodes inside the district)

node type 2 = nodes at the intersections of trail network and river system with existing trail bridges (61 nodes; all nodes inside the district)

node type 0 = all other nodes (total 419 nodes; 261 nodes inside the district and 158 nodes outside the district)

Figure 3-13: General layout of trail network, network nodes, rivers, service centers and villages



Spatial interaction and accessibility modeling will be run in the following three different scenarios of the river crossing condition:

1. assuming all the river crossing locations are accessible (no impedance for movement of people at any river crossing locations , i.e. all nodes of type 1 and 2 have trail bridges),
2. river crossings allowed only at nodes of type 2 (impedance created at node type = 1 as there are no trail bridges at these river crossing locations),
3. allocation of additional new trail bridges at node type = 1 (i.e. removing impedance at these locations by allocating additional new trail bridges) in poorly served areas identified in scenario # 2.

In order to have the insights on the people's interaction with the service centers and node's potential accessibility to service centers, the first two scenarios will be run. The first scenario is the desired situation of the interaction and potential accessibility with respect to river crossings and trail bridges on the trail network and spatial distribution of the existing service centers. The second scenario is the situation of the interaction and potential accessibility with respect to availability of trail bridges at river crossing locations that allow people to travel through the trail network with out barriers. In both scenarios interaction modeling will produce a total number of trips per service center and trail network travel distance to accomplish these trips. Likewise, in both scenarios accessibility modeling will produce node's accessibility index values to all the service centers. A comparison of number of trips per service center, network travel distance and node's accessibility index values will be made in order to further scrutinize and acquire information to allocate new bridges.

Interaction analysis requires a centers table with centers attraction items. For health services, 22 centers are assigned an attraction value based on the range of services available. The values assigned reflect the hierarchy of care available at the different types of health centers. These values are 100 for hospitals (n = 1), 50 for health centers (n = 1), 10 for health posts (n = 16) and 5 ayurvedic clinics (n = 4). For the 72 school centers the attraction values are set at 100 for secondary schools including a campus (n = 24), and 50 for lower secondary schools (n = 48).

Interaction modeling requires a node demand attribute table associated with trail network nodes. For the village development (settlement village) polygons that contain nodes, the node demand table assigns equal shares of population value to each node within the polygon. It is estimated that all the people in the settlement village areas (polygons) need health care services, and hence, they all travel to health service centers. So, the total demand will be equal to the population and will be distributed to the health service centers with respect to their supply (attraction). In the case of school, the demand is created only by the school age population which is about 40 percent of the total population. Accordingly, the total demand will be equal to the number of school age children and will be attracted by the available schools with respect to their supply (attraction item). Interactions will be run for health service centers and school separately. Analyses are done with the output interaction table in ArcMap.

Several mathematical functions are available to model the diminution of interaction and accessibility with increasing travel distance. Two types of distance-decay functions are provided within ARC/INFO. These are a power function and an exponential function. The power function provides a gentle cutoff to destinations, and the exponential function provides a steeper cutoff to destinations. The exponential function is typically used for computing interactions over a small distance, such as within a city, and the power function is used for interactions over a larger distance. As the analysis covers a wider geographical coverage (1,088 sq. km) the distance decay function with power of 2 is used. This function assumes that the probability of a trip to a destination declines at a constant rate as distance increases. The length of the trail network travel path was used for the distance decay impedance term.

The spatial interaction, represented by people traveling from the settlement village polygon nodes (P_i) to social service centers (P_j) follows a gravity type law. The expected interaction (I_{ij}) between the population at node (P_i) and service center at (P_j) located at a network distance d_{ij} are computed using the following equation:

$$I_{ij} = \frac{P_i P_j}{d_{ij}^{\;2}} \qquad \text{(Equation 3-1)}$$

Accessibility provides an aggregate measure of how accessible a location is to social services. The potential spatial accessibility of A_i to D_j are computed mathematically using the following equation:

$$A_i = \sum_{j=1}^{n} \frac{D_j}{d_{ij}^{\;2}} \qquad \text{(Equation 3-2)}$$

where, A_i is the accessibility value of node i, D_j is the attractiveness (supply capacity) of the service center locations (health service centers, schools), d_{ij} is the trail network distance from point (node) i to service center locations j and n is the number of service center locations.

The computed trips from nodes to service centers will be a relative measure of spatial interaction between the population in the village polygon nodes and service centers. Likewise, the computed spatial accessibility index values will be a relative measure of accessibility of each origin nodes with respect to destination service centers.

3.3.3 Bridge Prioritization

The bridge prioritization process adds bridges in tiers working outwards from the endpoints of the existing route network. As each tier of new bridges is added to the network, the number of trips expected over each new bridge is calculated. Once all potential bridges have been added, the new bridges are sorted in descending order on the Trips field. This produces a preliminary prioritization of the new bridges. Each bridge in the sorted list is checked to ensure that its previous node has been given higher priority. If the previous node has lower priority, it is moved ahead of the current bridge in the priority list. The result is an outward expansion of the route network that maximizes the total number of trips as each new bridge is added to the network. For detail see Appendix F.

Chapter 4
RESULTS AND ANALYSIS

4.1 Spatial Data Creation, Transfer and Integration

The first two objectives of the thesis - creation of digital data and a map, and integration of attribute data with the map features - were to form the basis for accessibility analysis related to the third and forth objectives (Section 1.3). This section of the thesis describes the various steps necessary to model and optimize accessibility, as well as the outcomes at each step. The detailed outlining of these steps has practical value, as one of the underlying goals of the thesis is to provide an approach for identifying optimal bridge site locations that could be replicated for other districts in Nepal.

The spatial data were created from the print paper maps, Transport Infrastructure Maps and Central Service Maps (Figure 3-9 and Figure 2-5), for Okhaldunga District, which is a typical hill district. The data acquired for this study were expected to have relatively high accuracy. The data were created with table digitizing with ESRI ArcMap, and were edited, cleaned and modified as necessary. The attribute data tables of trail bridges available in FoxPro and MS Access database systems were assessed and edited before integrating them into the map features.

A composite base map (Figure 4-1) was created for an overview of the spatial distribution of settlement villages, service centers, trail networks, river systems, proposed roads and physical geography of the district. This map basically contains the following map features in different map layers:

- district administrative boundaries showing district headquarters of neighboring districts;
- village development committee centers and administrative boundaries;
- river systems (major and minor rivers[20]);

[20] Major rivers cannot be crossed year-round without a bridge, while minor rivers can be crossed during dry seasons but sometimes they are quite risky and dangerous. Both major and minor rivers have turbulent flow with high gradient and current.

- contour lines (1,000 m interval), spot heights (m);
- trail networks (main and local trails[21]);
- road networks (proposed), airport;
- geographic coordinate grids (east and north coordinates);
- settlements locations (village centers);
- service centers locations
- district headquarters
- existing trail bridges (main trail bridges and local trail bridges[22]); and
- potential additional new trail bridges[23]

From the district-level planning perspective, the all trails have the same functional role in creating interactions and measuring accessibility between the population and the service centers. Similarly, the trail bridges categorized as main trail bridges and local trail bridges will make the same contributions to interaction and accessibility, depending on their locations on the trail network. Hence, all the trails in the district fall in a single trail network and, likewise, the existing trail bridges are treated as one set, regardless of bridge type and implementation approach, which may differ depending on the

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[21] Main trails are those trails that link important central places like district headquarters and road-heads. All other trails that connect local communities are defined as local trails.

[22] Trail bridges on main trails are defined as main trail bridges while on local trails they are defined as local trail bridges.

[23] The locations of the potential additional new trail bridges were identified at the intersection point of the trail networks and river systems where there is no trail bridge existing and where one might be required to maximize the accessibility to social services.

specific location and topography. Some map outputs are illustrated in Figure 4-1, Figure 4-2 and Figure 4-3. Figure 4-1 depicts general layout of the district with trail, trail bridge, river and service center locations. Figure 4-2 and Figure 4-3 show some attributes of the map features.

Figure 4-1: A Transport Infrastructure Map of Okhaldhunga District

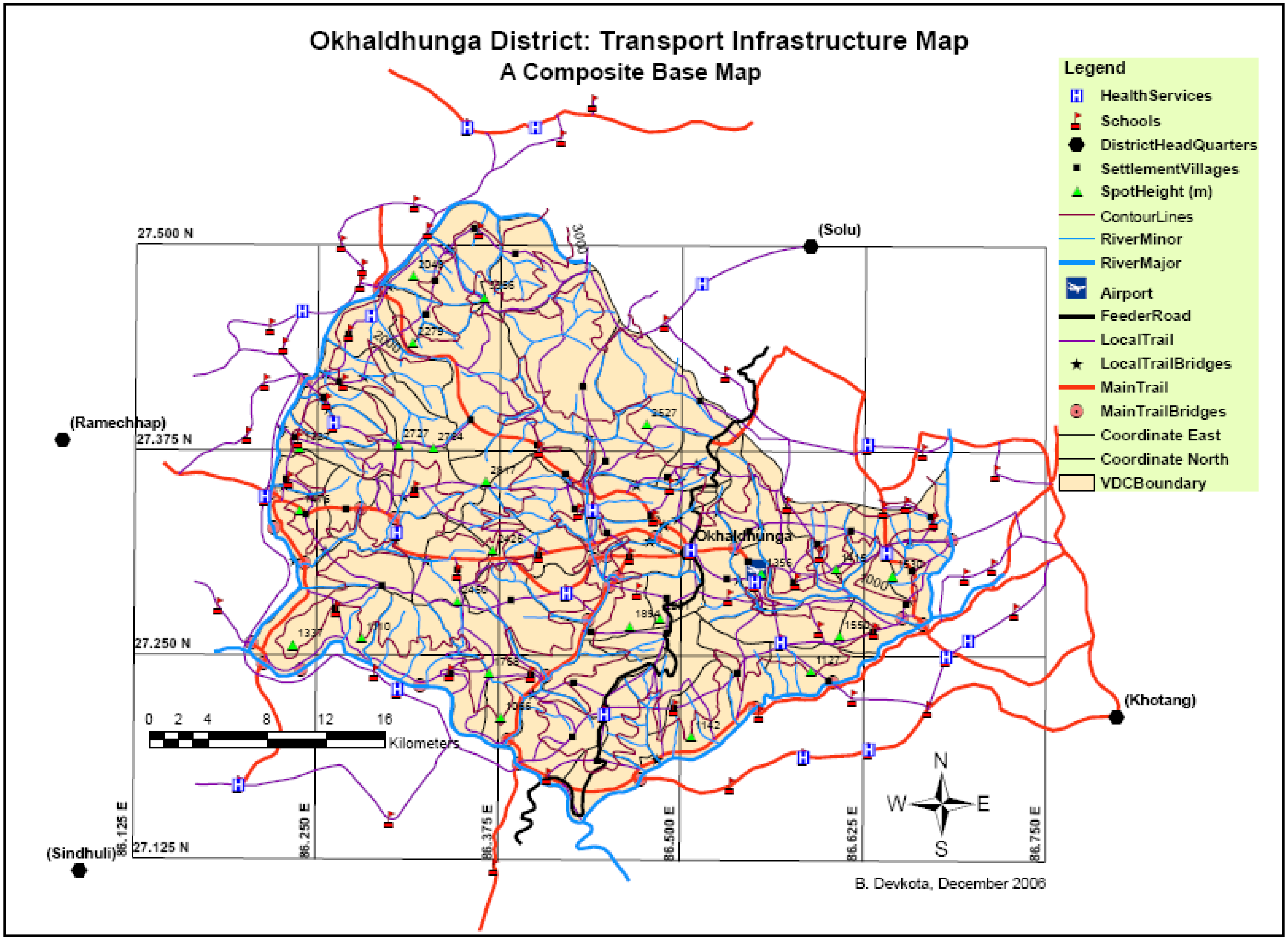


Figure 4-2: Integration of trail bridge attribute data with the map features

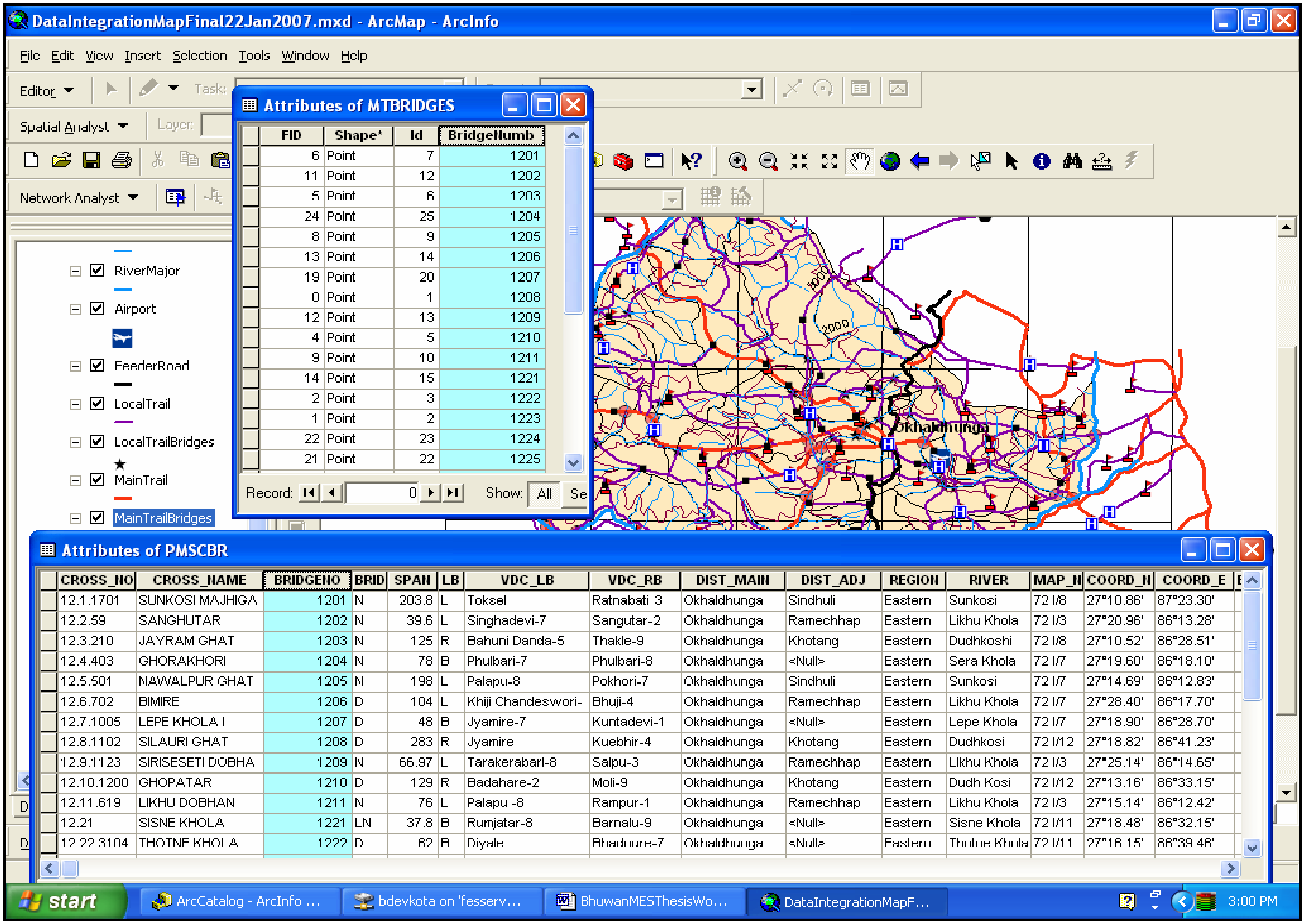
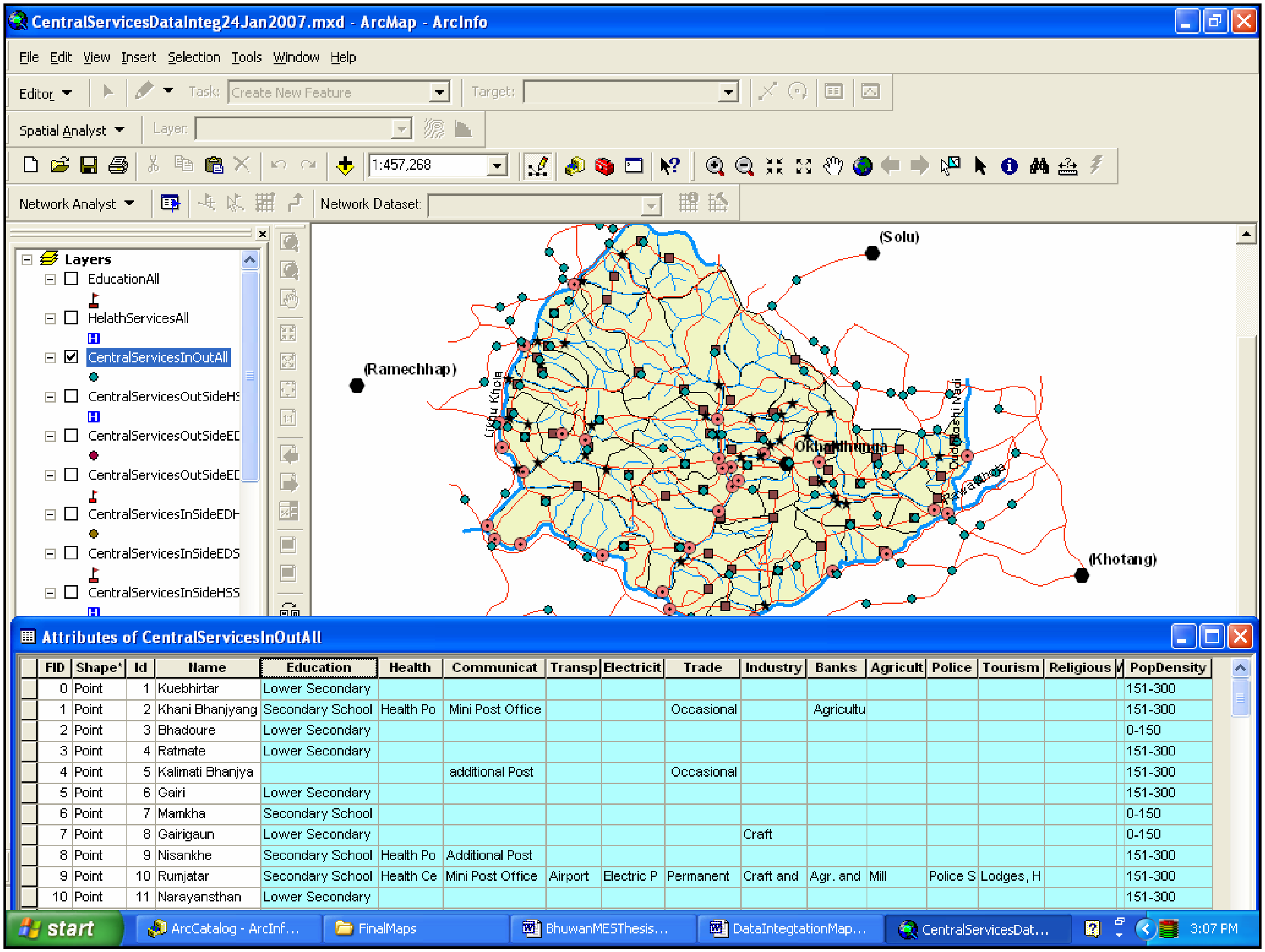


Figure 4-3: Integration of attribute data of social services with the map features



4.2 Spatial Analysis

In order to assess the existing accessibility conditions across the district, analysis is carried out with a district-level planning perspectives. Spatial interaction and potential accessibility are viewed across the district administrative boundary and not confined to small village settlement polygons. This provides the district planner an opportunity to assess accessibility situations across the district and also provides information on poorly served areas where additional new trail bridges may require.

All spatial data analysis was undertaken using ArcGIS. The analysis was focused on social service centers that have health care and educational facilities. To assess the desired and existing interaction and accessibility conditions, the first two scenarios of spatial interaction and accessibility were run for health care services and schools, as described in the methods, Section 3.3.2:

Figure 4-4 illustrates the general layout of trail network, rivers, nodes, service centers (example: health service centers) and the village boundary for scenario # 1 when all the nodes located at river crossing locations are assumed accessible. Figure 4-5 shows the general layout for scenario # 2. The nodes type 1 as shown in Figure 4-5 create a barrier as these nodes are located at river crossing locations and do not have trail bridges.

Figure 4-4: Layout of all nodes, trail network, rivers, service centers and village boundary

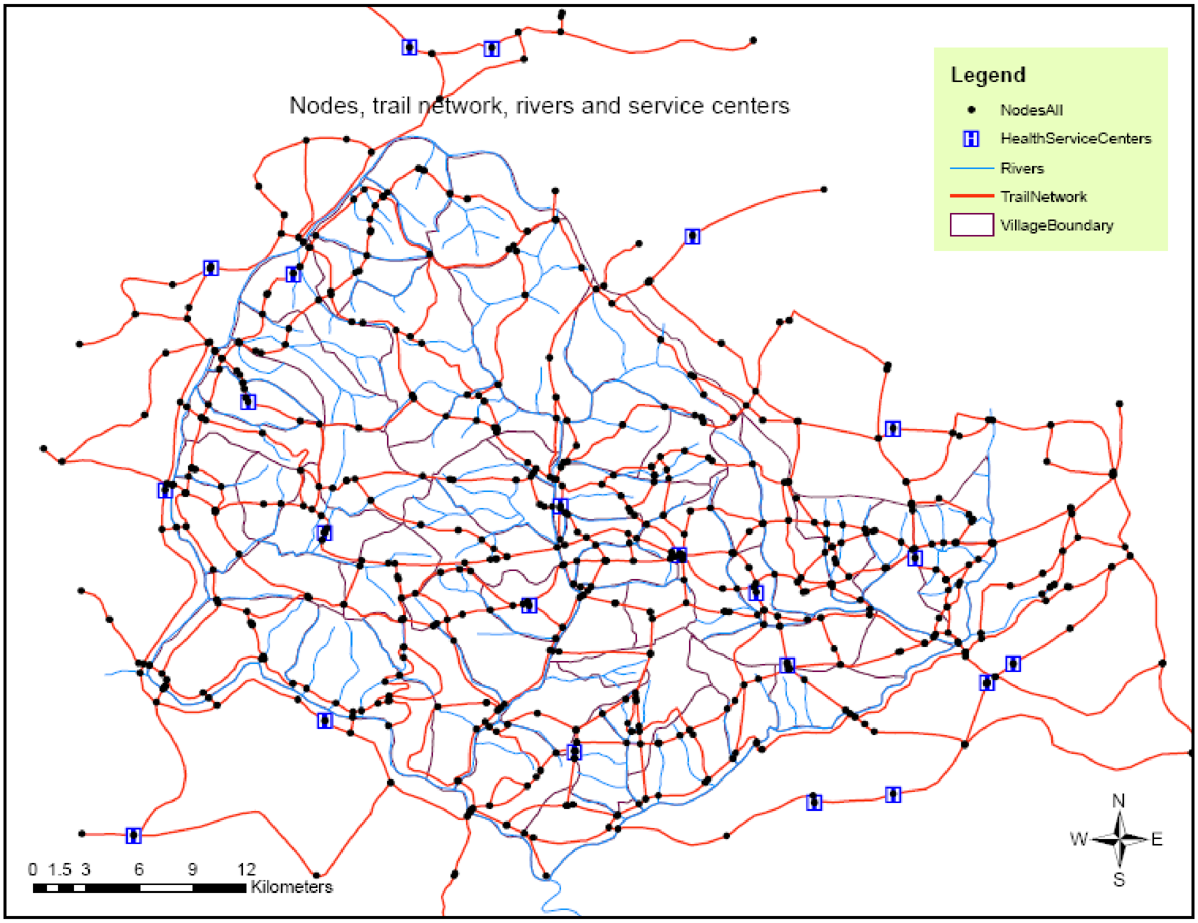
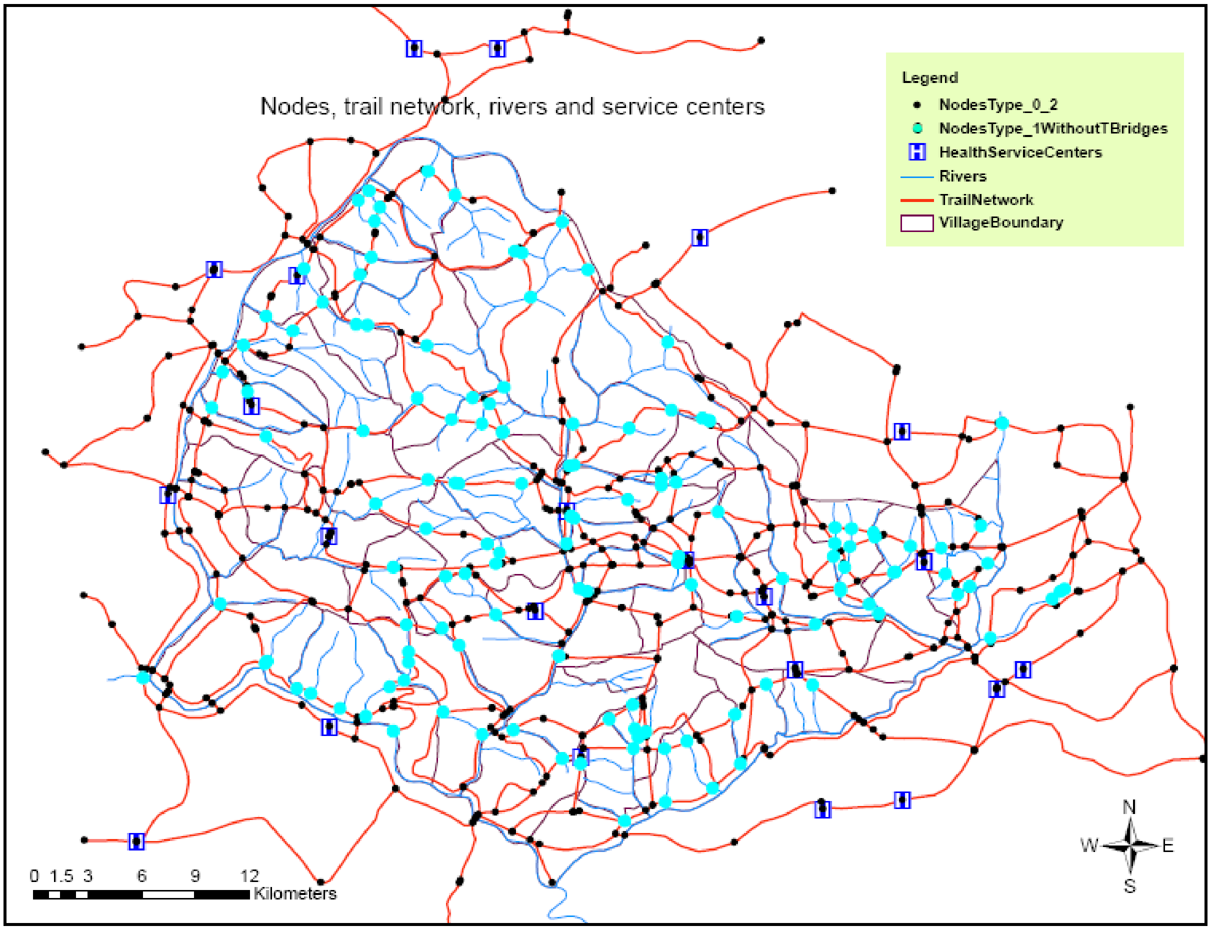


Figure 4-5: Layout of all nodes, nodes without trail bridges, trail network, rivers, service centers and village boundary



4.2.1 Spatial Interaction Analysis

4.2.1.1 Health Care Service Centers

<u>Scenario #1</u>: The first scenario that was modeled is the ideal situation, i.e.., when all the river crossing locations are accessible (no impedance for movement of people at any river crossing locations, i.e. all river crossing locations have trail bridges). In this scenario, it is assumed that there are no restrictions or barriers at all the river crossing locations. It is the desired situation of the potential accessibility with respect to river crossings and trail bridges on the trail network and spatial distribution of the existing service centers.

All the population allocated to the 458 nodes will require health care services. Depending on the population, each node generates a number of trips. People walk along the trail network to the nearest health care center. The nodes located outside the district boundary produce no trips as these nodes do not have any share of the village population. This is because the interaction analysis is being done for the population within the district boundary. However, the people have opportunities to acquire services from the centers located inside or outside the district. All 22 health care service centers attract these trips depending on their respective supply capacity and proximity to the polygon nodes.

For interaction analysis, a health care service centers table is created with attributes of each health center's attraction (supply) items. The "Make Centers Table" script tool was used to create a centers table based on point features in the health services shape file. The "Find Nearest Node" function uses the "Near" tool to set the NEAR_FID item for each health care service center in the centers table. The output centers table is a dbf file containing ID, NEAR_FID and SUPPLY fields (Table 4.1).

Table 4.1**:** Health service centers table in scenario # 1

ID	NEAR_FID	SUPPLY*[24]
1	328	10
2	482	10
3	393	50
4	323	100
5	567	10
6	239	10
7	411	10
8	58	10
9	123	10
10	285	5
11	222	10
12	534	10
13	53	5
14	7	10
15	8	10
16	40	10
17	155	10
18	479	10
19	496	10
20	608	5
21	584	5
22	588	10

[24] SUPPLY item is the supply capacity or attractiveness of health care service centers which is assigned based on their service capacity; Hospital 100, Health center 50, Health post 10 and Ayurvedic clinic 5.

Table 4.2**:** Health service demand table in scenario # 1

FTRL2C_	FREQUENCY	SUM_DEMAND
1	1	0
2	1	0
3	1	0
4	1	0
5	1	0
6	1	0
7	1	0
8	1	0
9	1	0
10	1	0
11	1	0
12	1	0
13	1	0
14	1	0
15	1	414
16	1	414
17	1	414
18	1	0
19	1	0
20	1	227
21	1	0
22	1	227
23	1	414
24	1	227
25	1	227
26	1	330
contd…	contd…	contd…
…	…	…
614	1	0
615	1	237
616	1	0
Total sum demand		141,289

Spatial interaction modeling requires a demand attribute associated with trail network nodes. In order to estimate trips generated at each node and trips attracted by each health care service center, a health service node demand table was created. The "Node Demand" script tool was used to estimate the number of trips produced by the people at each node based on the polygon population. For polygons that contain nodes, the "Node Demand" script tool assigns an equal share of polygon population to each node within the polygon. The output demand table is a dBase table containing trail network node internal identifier item (FTRL2C_) and the "Demand" item for each node. Total demand items or trips created at each node would be equal to the total population within the respective village polygon. Total sum demand created by the 616 nodes is equal to 141, 289 which is equal to the sum of the population of all the village polygons (Table 4.2).

Interaction analysis was run in the workstation ArcGIS, creating an interaction table using the centers table and node demand table. From-to impedance was taken as the trail network length from node to service center. To run the interaction analysis in workstation ArcGIS, it was necessary to convert the demand and centers dBase table into info tables, and to define a relation between the demand table and network coverage based on the internal node identifier. These steps were performed using the interaction script tool. The interaction script validates all input parameters, converts dBase file inputs to info tables, runs the interaction analysis, converts the output info table into a dBase file, and finally, deletes all temporary info tables created during processing. The output interaction table is a dBase table containing origin, destination, trips, distance and other items.

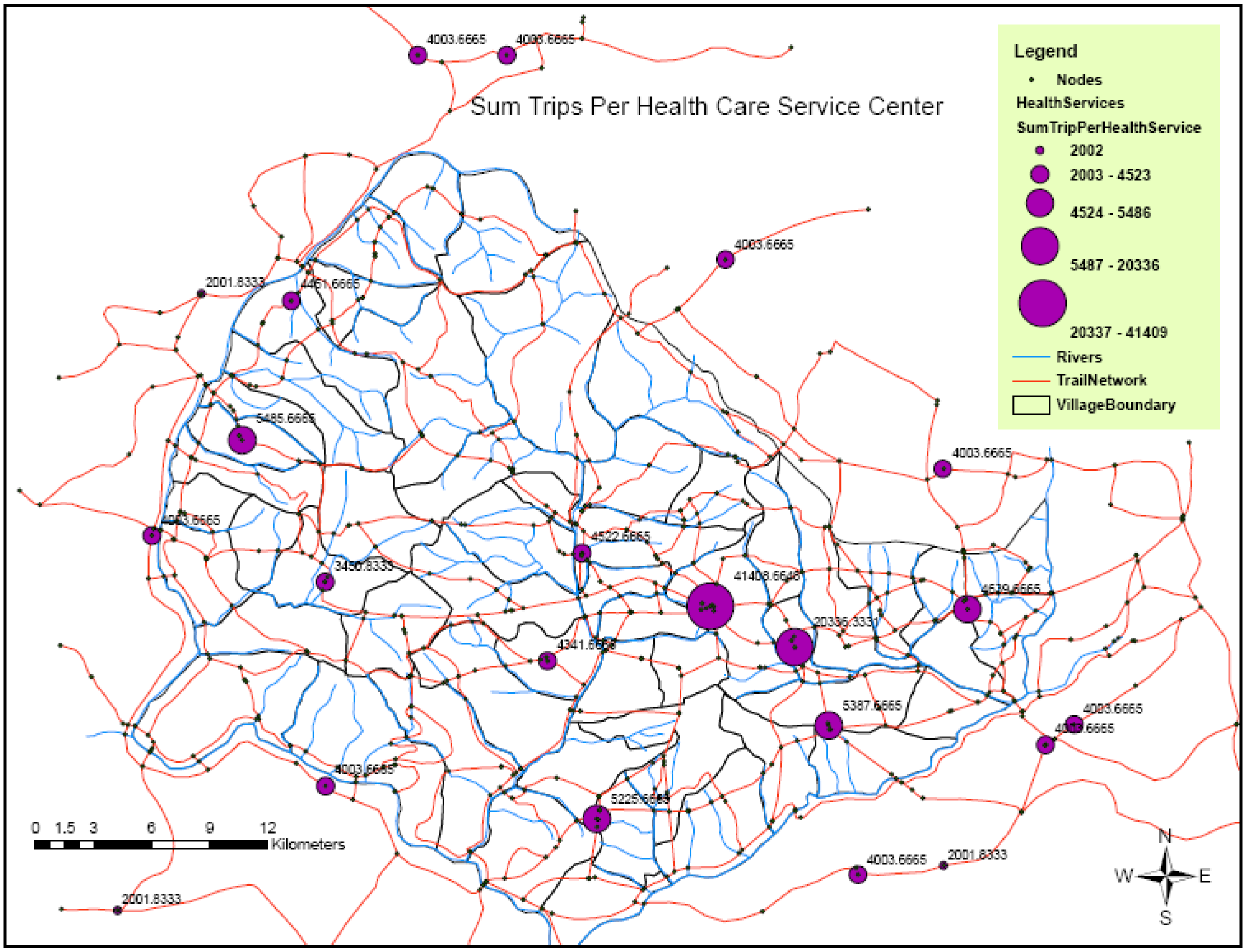
The output interaction table illustrates the aggregate number of trips attracted by each of the health care service centers and the trail network distance possible to travel by people to accomplish these trips. The results are shown in Table 4.3. A view of the map of the district with sum of trips per health care service center is shown in Figure 4-6. The total demands created at each node are attracted by different health care service centers and equal to the total population of the village polygons which is 141,289.

In order to obtain the sum of trips per health care center, the interaction table was summarized in the DESTINATION field calculating the SUM of P_Cost field. The Sum_P_Cost field in the summary table (TripsPerHCenter) represents the estimated trips to each service center. The output results are visualized in the map (Figure 4-6) by joining the summary table to HealthService shape file using Near_FID and Destination items. Likewise, in order to obtain the sum of trail network travel distance to accomplish the total trips, the interaction table was summarized in the DESTINATION field calculating the SUM of Distance field. The Sum_Distance in the summary table represents the estimated trail network travel length to each service center. The output results are visualized in the map (Figure 4-7) by joining the summary table and HealthService shape file.

Table 4.3**:** Attributes of spatial interaction in scenario #1

Sum of Trips per Health Service Center and Sum of Travel Distances from nodes to per Health Service Center						
Id	Name	Health Service Type	Supply	Destination ID	Sum Trips Per Health Care Center	Sum Travel Distance(km)
1	Khani Bhanjyang	Health Post	10	328	4,640	12,038
2	Nisankhe	Health Post	10	482	5,388	10,212
3	Rumjatar	Health Centre	50	393	20,336	8,916
4	Okhaldhunga	Health Post, Hospital	100	323	41,409	7,720
5	Mane Bhanjyang	Health Post	10	567	5,226	10,440
6	Rampurtar	Health Post	10	239	4,523	7,615
7	Chyanam	Health Post	10	411	4,342	8,378
8	Chandisthan	Health Post	10	58	4,452	14,166
9	Mulpadhera	Health Post	10	123	5,486	12,395
10	Ghorakhori	Ayurvedic Clinic	5	285	3,451	10,153
11	Sanghutar	Health Post	10	222	4,004	13,198
12	Swalpa	Health Post	10	534	4,004	13,455
13	Ghyangdanda	Ayurvedic Clinic	5	53	2,002	15,561
14	Bhandar	Health Post	10	7	4,004	21,384
15	Cholakharka	Health Post	10	8	4,004	22,390
16	Gorakhani	Health Post	10	40	4,004	14,315
17	Salyan	Health Post	10	155	4,004	13,150
18	Kharpa	Health Post	10	479	4,004	15,056
19	Lamidanda	Health Post	10	496	4,004	14,722
20	Bahuntilpung	Ayurvedic Clinic	5	608	2,002	18,640
21	Mahadevsthan	Ayurvedic Clinic	5	584	2,002	16,379
22	Durchhim	Health Post	10	588	4,004	16,563
	Total				141,289	296,846

Figure 4-6: A view of sum of trips attracted per health care service center in scenario # 1



The results of the spatial interaction indicate the levels of relative ease or difficulty in accessing available services for the people at each health care service center. Figure 4-6 and Figure 4-8 show the values of aggregate trips attracted by each of these health care service centers. The trips attracted by health care service centers with supply item 100 (hospital) are the highest followed by the supply item 50 (health center). However, these centers have relatively shorter aggregate network travel distance compared to other centers where people are required to travel longer distance with relatively lower number of trips attracted. The service centers with higher number of trips are located near or in close proximity to the district headquarters. Also, the village settlement polygons in this region have relatively high density of population compared to other locations.

Figure 4-7**:** A view of sum of trail network travel distance per health care service center in scenario # 1

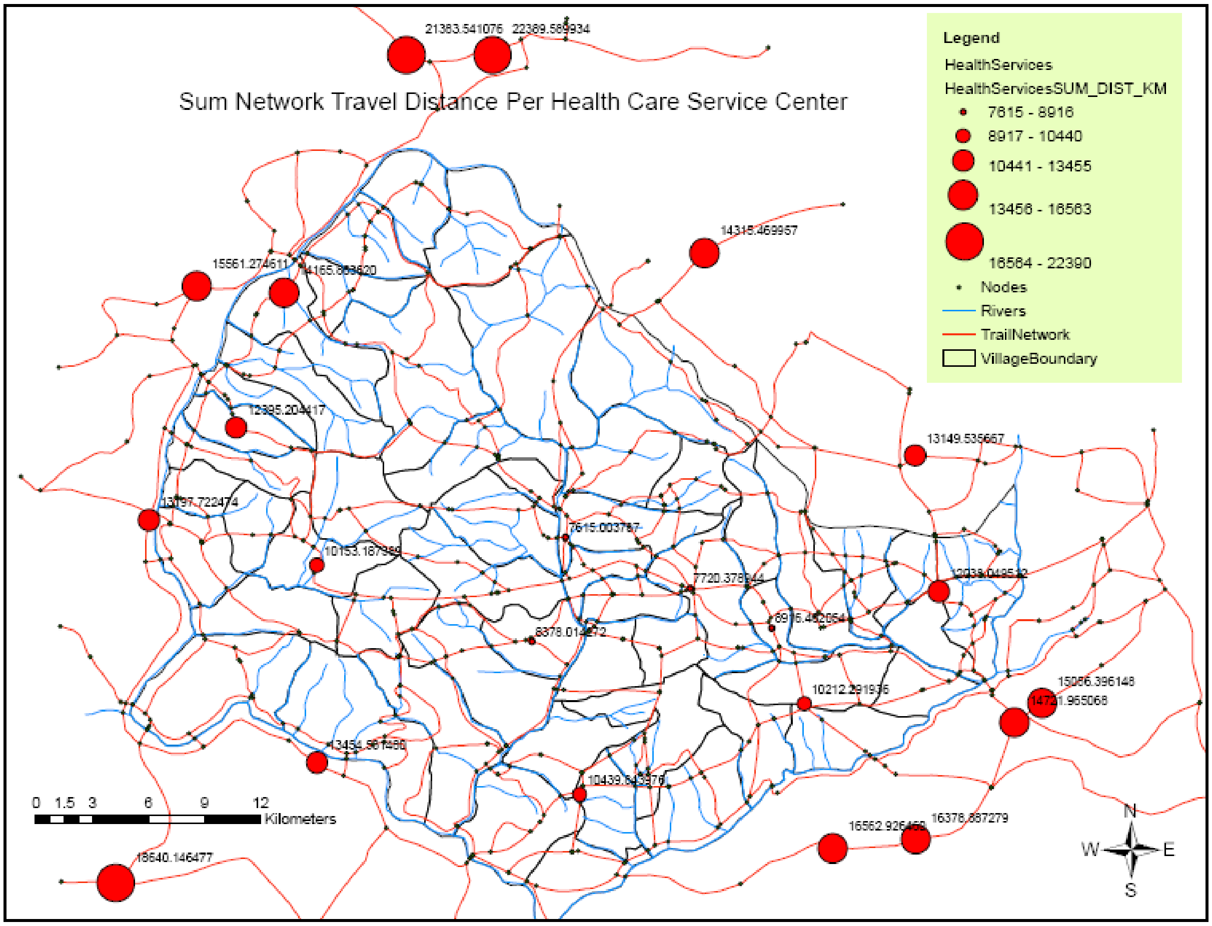


Figure 4-7 and Figure 4-9 show the aggregate trail network travel distance that possibly would make by people to each health care service center. The results show that the sum of trail network travel distance to the centers located near or at the district headquarters is comparatively lower than the centers located farther away from the district headquarters. It indicates that people in the village settlements located away from the district headquarters are required to walk longer distance to access the facilities of the health care centers.

Figure 4-8: Sum of trips attracted per health care service centers in scenario # 1

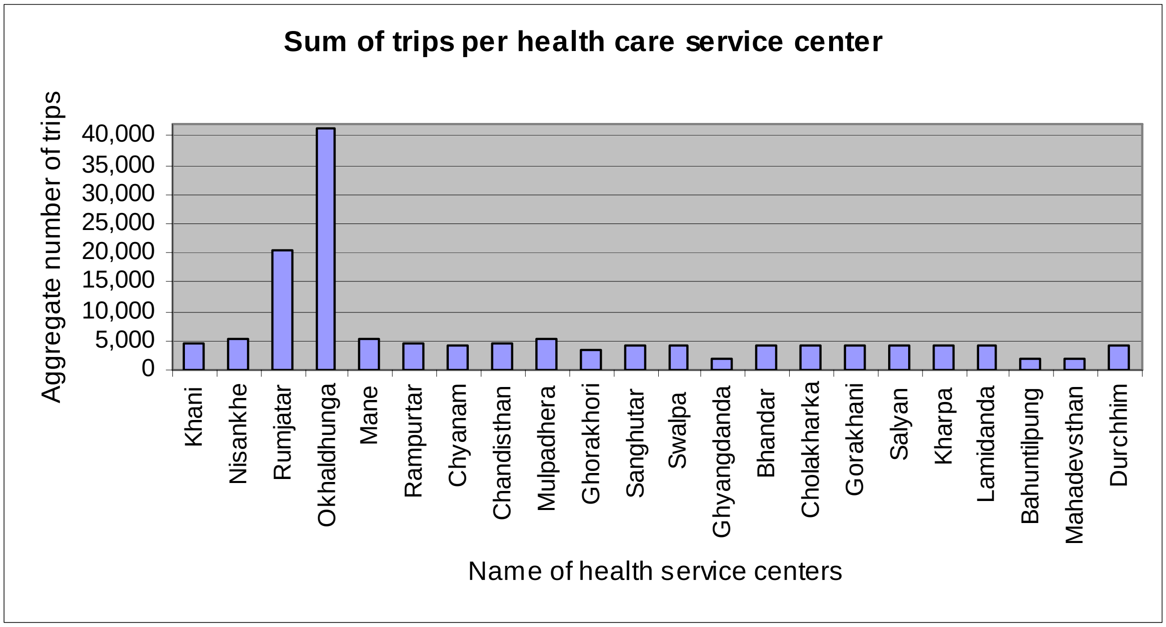
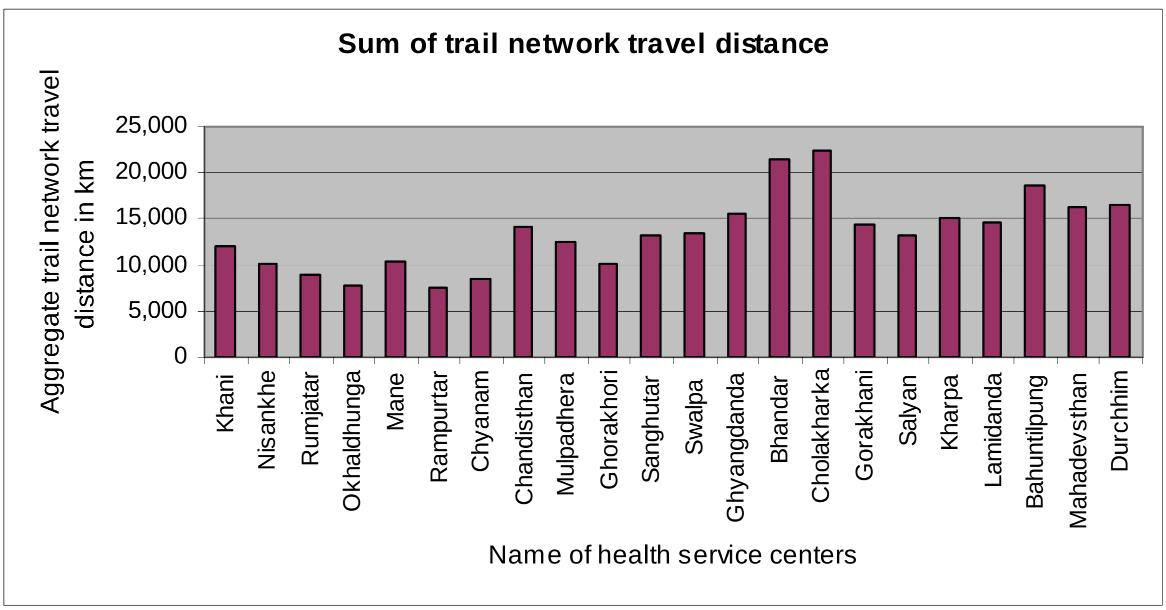


Figure 4-9: Aggregate trail network travel distance in km from nodes to health care service centers in scenario #1



In summary, scenario # 1 is the desired situation where people are able to access the closest health centre. This is the hypothetical situation where all the river crossing locations have trail bridges. The interaction results indicate the service gap for the people in village settlements located farther away from the district headquarters. Clearly, not all people in the district would have equal or adequate access to health care - even in this ideal situation.

Scenario #2: The second scenario involved spatial interaction and accessibility modeling with an impedance created at the river crossing locations that are currently without trail bridges (impendence created at the node type = 1, as there are no trail bridges at these river crossing locations). This scenario best captures the current situation, where some river crossings have travel bridges and others do not.

The methods and steps followed were analogous to run for scenario # 1. The centers table and node demand table created in scenario # 1 are used as these tables are the same in all the scenarios. The interaction table was created with turn table (ebtrials.trn) and turn impedance item (TRNIMP). All type 1 nodes do not allow people to travel through these nodes. Hence, people will have to travel longer distance by making a detour or in some instances they even might be deprived from accessing health care services as they might be isolated.

The sum of the trips attracted by each health care service center and the sum of the trail network length traveled by people to complete these trips are calculated. The output results are shown in Table 4.4. Figure 4-12 shows aggregate number of trips per health care service center and Figure 4-13 shows the values of aggregate travel distance at each health care service center.

In this scenario # 2 the aggregate sum of trips per center is less than the total population in the village polygons. The result of interaction indicates that some 24,926 people (difference in number of trips = 141, 289 - 116,363 = 24,926) could not make a trip to a health care centre. As well, due to impedances (barriers) at the certain river crossing locations, some people are required to make longer than what occurred in Scenario #1. In total, people are required to travel an additional 155,900 km (difference in trail network travel length = 452,746 - 296,846 = 155,900 km) in making a total of

116,363 trips (Table 4.4). The relationship between the number of trips to a service center and sum of network travel distances to a service centre is virtually zero, as illustrated by a regression analysis. This is because of physical geography and unequal access. Put simply, some river crossings locations create barrier for movement of people along the trail network, and also some nodes are totally isolated from health care services. There are other variables that possibly explain the relative accessibility of the different service centres, the most important being population distribution.

Table 4.4: Attributes of spatial interaction in scenario # 2

Sum of Trips per Health Service Center and Sum of Travel Distances from nodes to per Health Service Center						
Id	Name	Health Service Type	Supply	Destination ID	Sum Trips Per Health Care Center	Sum Travel Distance (km)
1	Khani Bhanjyang	Health Post	10	328	2,022	25,745
2	Nisankhe	Health Post	10	482	4,496	18,322
3	Rumjatar	Health Centre	50	393	14,341	18,880
4	Okhaldhunga	Health Post, Hospital	100	323	19,720	20,215
5	Mane Bhanjyang	Health Post	10	567	4,135	22
6	Rampurtar	Health Post	10	239	6,589	24,989
7	Chyanam	Health Post	10	411	19,126	18,867
8	Chandisthan	Health Post	10	58	2,168	9
9	Mulpadhera	Health Post	10	123	5,319	27,702
10	Ghorakhori	Ayurvedic Clinic	5	285	7,988	24,087
11	Sanghutar	Health Post	10	222	9,023	22,206
12	Swalpa	Health Post	10	534	4,954	17,336
13	Ghyangdanda	Ayurvedic Clinic	5	53	3,050	26,553
14	Bhandar	Health Post	10	7	1,282	34,103
15	Cholakharka	Health Post	10	8	1,102	34,885
16	Gorakhani	Health Post	10	40	976	26,574
17	Salyan	Health Post	10	155	1,309	23,603
18	Kharpa	Health Post	10	479	2,240	17,541
19	Lamidanda	Health Post	10	496	2,550	17,090
20	Bahuntilpung	Ayurvedic Clinic	5	608	1,197	21,005
21	Mahadevsthan	Ayurvedic Clinic	5	584	851	16,614
22	Durchhim	Health Post	10	588	1,926	16,398
	Total				116,363	452,746

Figure 4-10**:** A view of sum of trips attracted per health care service center scenario # 2

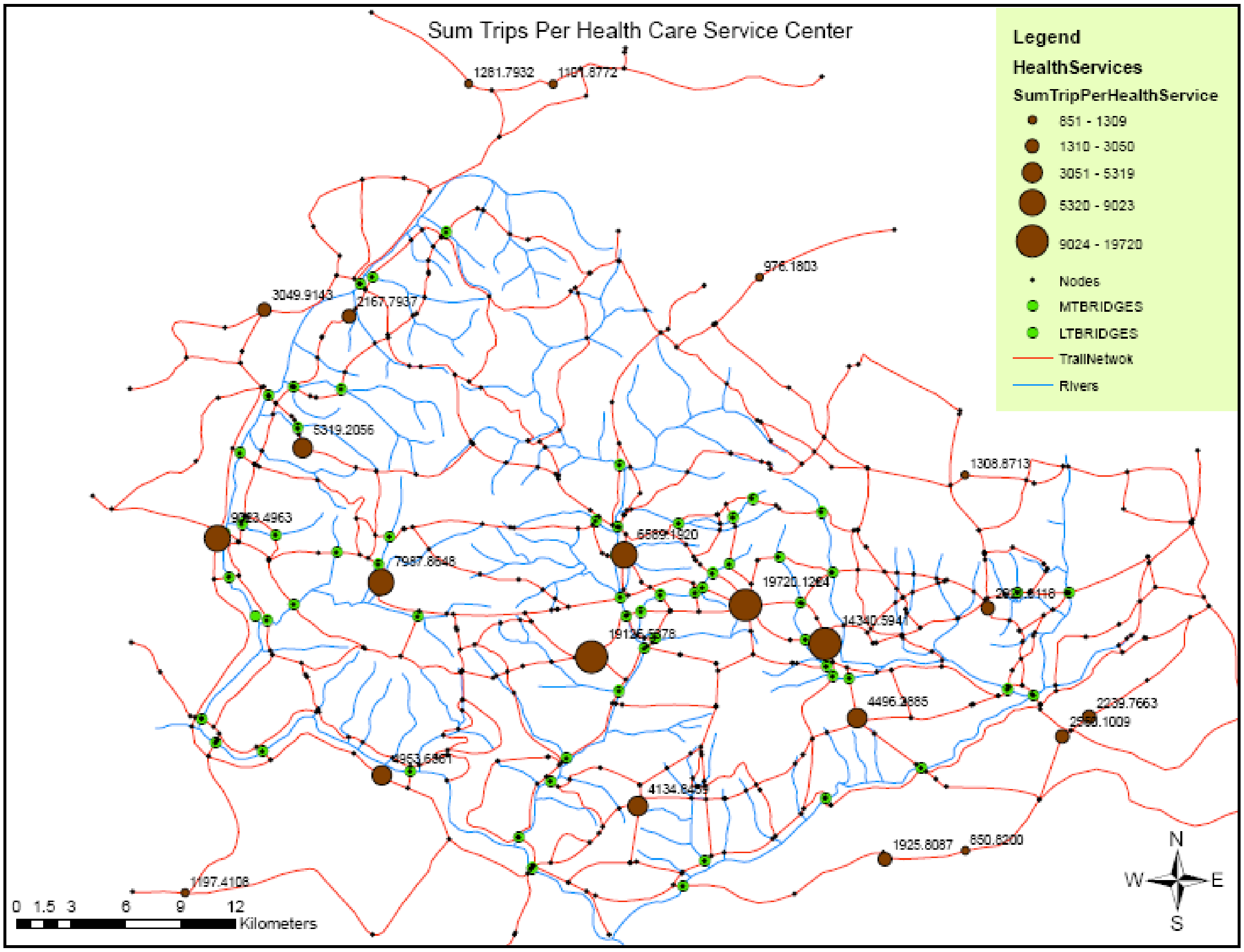


Figure 4-10 and Figure 4-12 show that the trips attracted by the health care service centers are higher in instances where centers are accessible, whereas, the centers that have difficulties in accessibility due to lack of trail bridge at river crossing locations attract fewer trips. In some instances people are isolated and are unable to access health care services at all; hence the regions do not produce any trips. These areas are of interest while addressing the issue of improving accessibility to the available service centers.

Figure 4-11: A view of sum of trail network travel distance per health care service center in scenario # 2

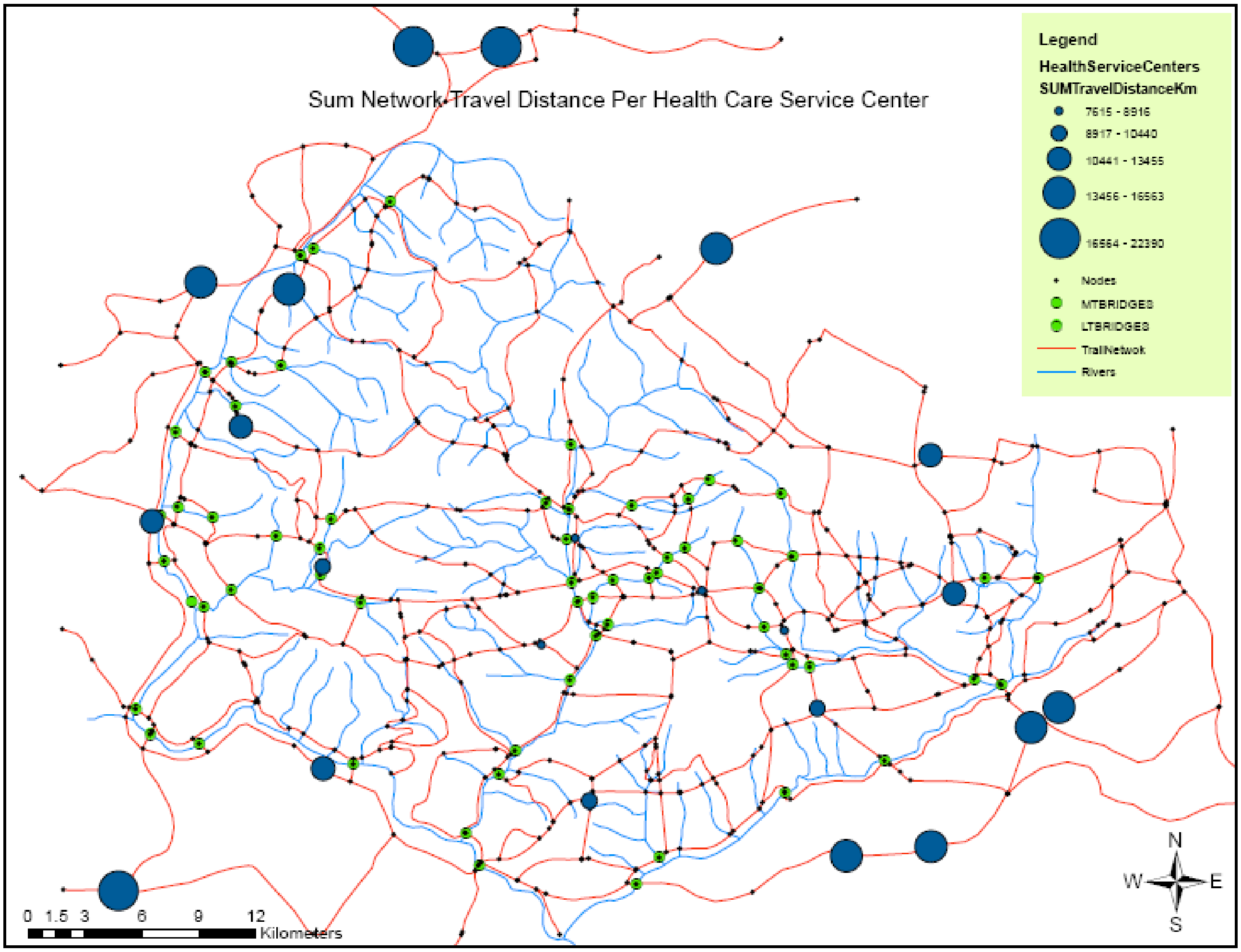


Figure 4-11 and Figure 4-13 show the trail network travel distances that people would currently make to each health care service center, assuming that every person needed health care exactly once. The centers that are accessible because of the location or proximity of existing trail bridges have relatively lower travel distances associated with their use. In particular, the settlement villages located near or at the district headquarters are comparatively better off than those located farther away.

In summary, the spatial patterns of interaction are considerably different between the two scenarios. In the hypothetical case where all trails that intersect rivers have bridges, the total accessibility to health care services is considerably greater.

Figure 4-12: Sum of trips attracted per health care service centers in scenario # 2

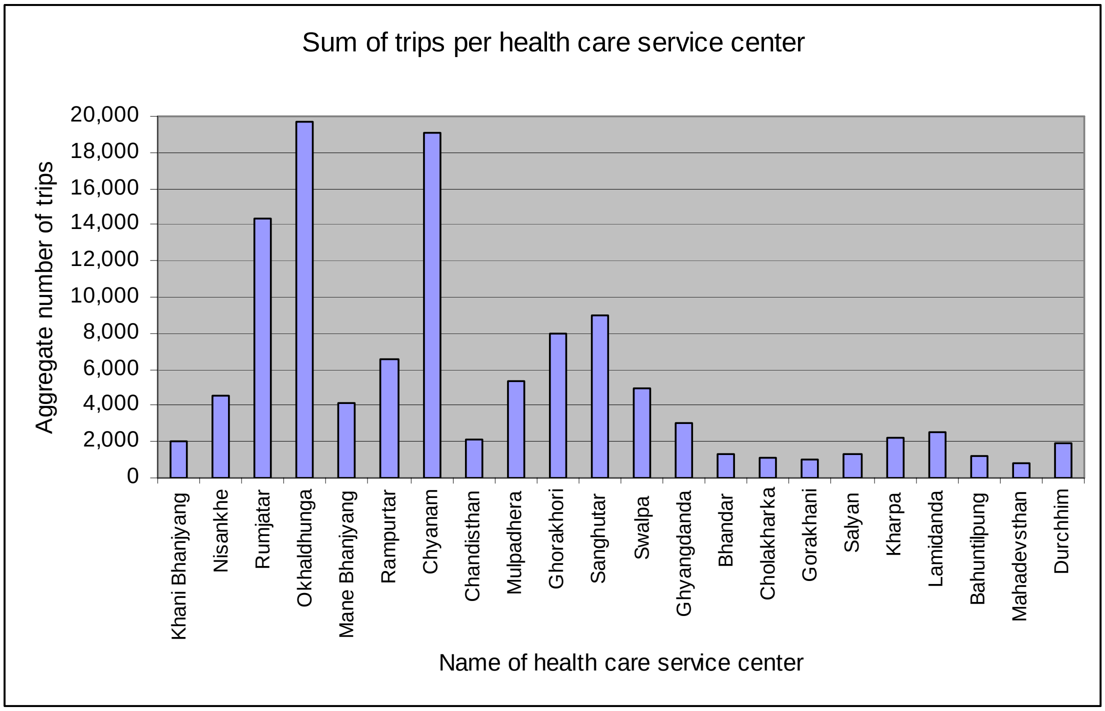
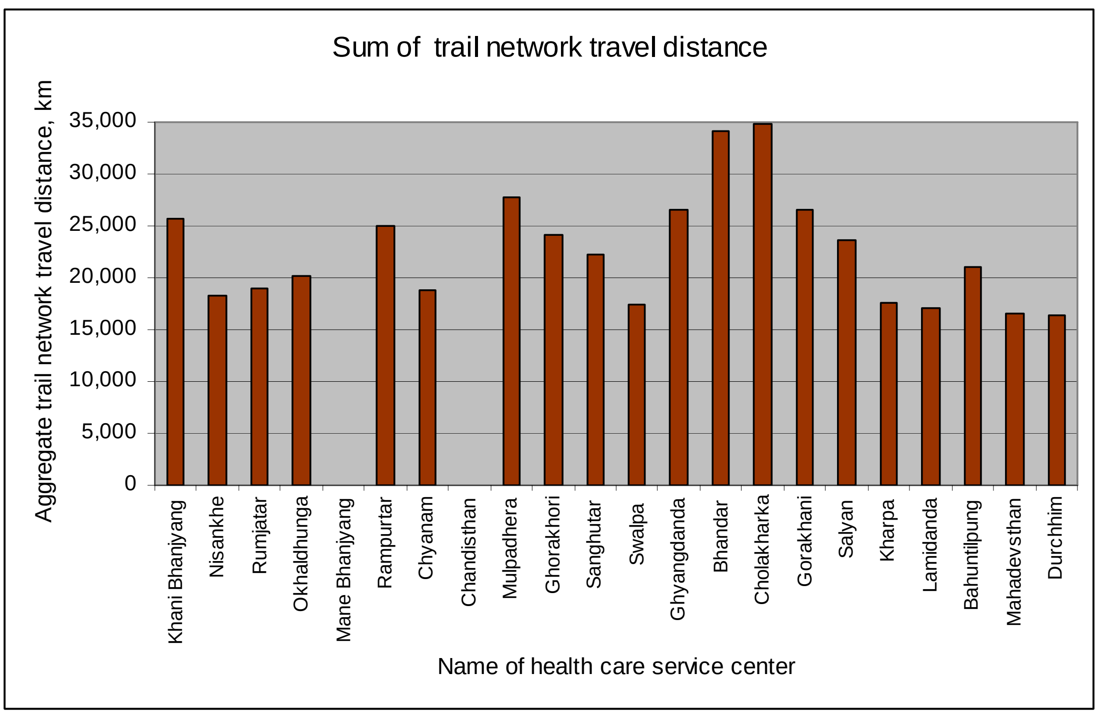


Figure 4-13: Aggregate trail network travel distance in km from nodes to health care service centers in scenario # 2



4.2.1.2 Schools

The method used to allocate trips to schools is analogous to that for health care centers. The only difference is that the total demand is based on the school age population of each village polygon. Since there is no available data on the age distribution for each village, the district average of 40 percent of the total population is used. The results of the spatial interaction analysis for schools follow a similar pattern as for the health care service centers. However, the sum of trips to schools and the trail network travel distance are different due to differences in both the population size and the number of available service centers (school). With respect to the latter, educational facilities are usually widespread whereas the health care service centers are sparsely distributed. The output attribute tables of spatial interaction, maps and charts for educational facilities are presented in Appendix E.

4.2.2 Potential Accessibility Analysis

4.2.2.1 Health Care Service Centers

Just as in the spatial interaction modeling, potential accessibility analysis was conducted for two contrasting scenarios. Again Scenario #1 represents the hypothetical situation were all river crossing locations have bridges, and Scenario #2 reflects the current system of trail bridges.

Potential accessibility analysis is run in ArcMap using the data from the centers and interaction output tables. A new field called “ACCESS” was added into the interaction table. The centers table and interaction table were joined using the “Destination” and “Near_FID” items. Calculation of access values was done in the ACCESS field. The calculated ACCESS values represent the contribution of the particular destination (service center) to the origin node’s accessibility. The interaction table was summarized on the ORIGIN item calculating the SUM of the ACCESS item. This process produced a table with one record for each origin node in which the SUM_ACCESS item is the node’s accessibility to service centers. In summary, the calculated nodes’ access values shown in Table 4.5 were obtained from the expression in Equation 3.2 (Section 3.3.2).

The results for Scenario #1 are summarized in Table 4.5 and illustrated in Figure 4-14. Figure 4-14 indicates relative accessibility of each node to all the health care service centers. The accessibility values are highly variable, from 0.36 to 102.51. These values depend on the supply item of the health care service center and the network distance from nodes to respective service centers. The nodes with high accessibility values indicate their location is in close proximity to service centers. A larger sum of accessibility values indicates better accessibility and smaller accessibility value indicate poor accessibility.

Table 4.5: Node's accessibility values to health care service centers scenario #1

ORIGIN NODE	SUM_ACCESS
15	0.3887
16	0.3824
17	0.3814
20	0.5946
22	0.4897
23	0.3659
24	0.5114
25	0.5115
26	0.3655
27	0.6803
28	0.4714
30	0.4426
31	0.4501
32	0.4511
33	0.4462
34	0.4152
35	0.4152
36	0.4525
39	2.0455
45	0.4290
46	3.8108
47	3.7831
48	0.4227
49	0.4306
50	0.4405
51	0.5295
52	10.4791
54	0.5833
56	0.6099
57	0.6342
58	10.4735
65	0.6981
66	0.9003
67	2.9438
68	0.8764
contd…	contd…
…	…
270	5.6171
271	2.5303
272	14.6431
600	1.0268
602	0.7565
603	0.7565
604	0.9288
606	0.6749
611	0.6560
615	0.4999

Figure 4-14: A view of node's accessibility to health care service centers in scenario # 1

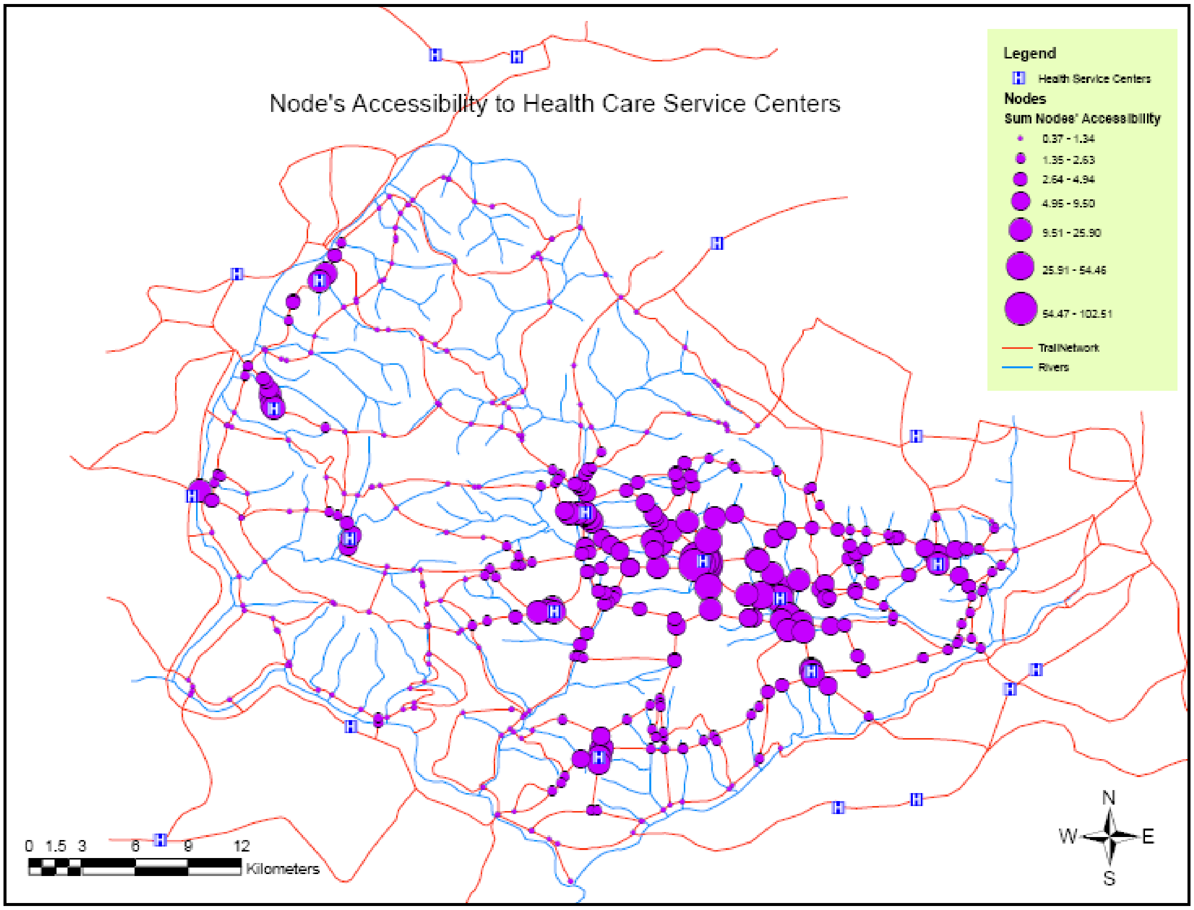


Figure 4-14 depicts the nodes' relative accessibility to all health care service centers. The nodes located near the district headquarters have relatively higher accessibility values compared to the nodes located in the northwest and southwest part of the district. Because the assumption of scenario # 1 is that all the river crossing locations are accessible, all the 458 nodes are somewhat accessible. Their values indicate their relative accessibility to all the service centers. Higher values indicate greater levels of accessibility.

For Scenario # 2, modeling is done with an impedance created at the river crossing locations that currently are without trail bridges (impendence created at the node type = 1, as there are no trail bridges at these river crossing locations). Potential accessibility analysis is run in ArcMap using the data from the centers and interaction tables following the procedures analogous to scenario #1. As the nodes type 1 create a barrier in the trail network, the turn table and turn impedance item (TRNIMP) were created to produce an output interaction table with a turn impedance. The Sum_Access item in Table 4.6 is the node's accessibility value to all the health care service centers.

Table 4.6: Node's accessibility values to health care service centers scenario # 2

ORIGIN NODE	Sum_ACCESS
27	0.1427
39	0.2106
46	0.2402
47	0.2399
52	10.1972
54	0.3972
57	0.1273
58	10.0000
65	0.4920
66	0.1532
67	2.4502
68	0.1503
69	2.2561
71	0.1381
72	0.5889
75	1.1184
78	0.1216
84	0.5371
85	0.2418
contd …	Contd …
…	…
604	0.2430
606	0.2200
611	0.2191
615	0.1791

Figure 4-15: A view of node's accessibility to health care service centers in scenario # 2

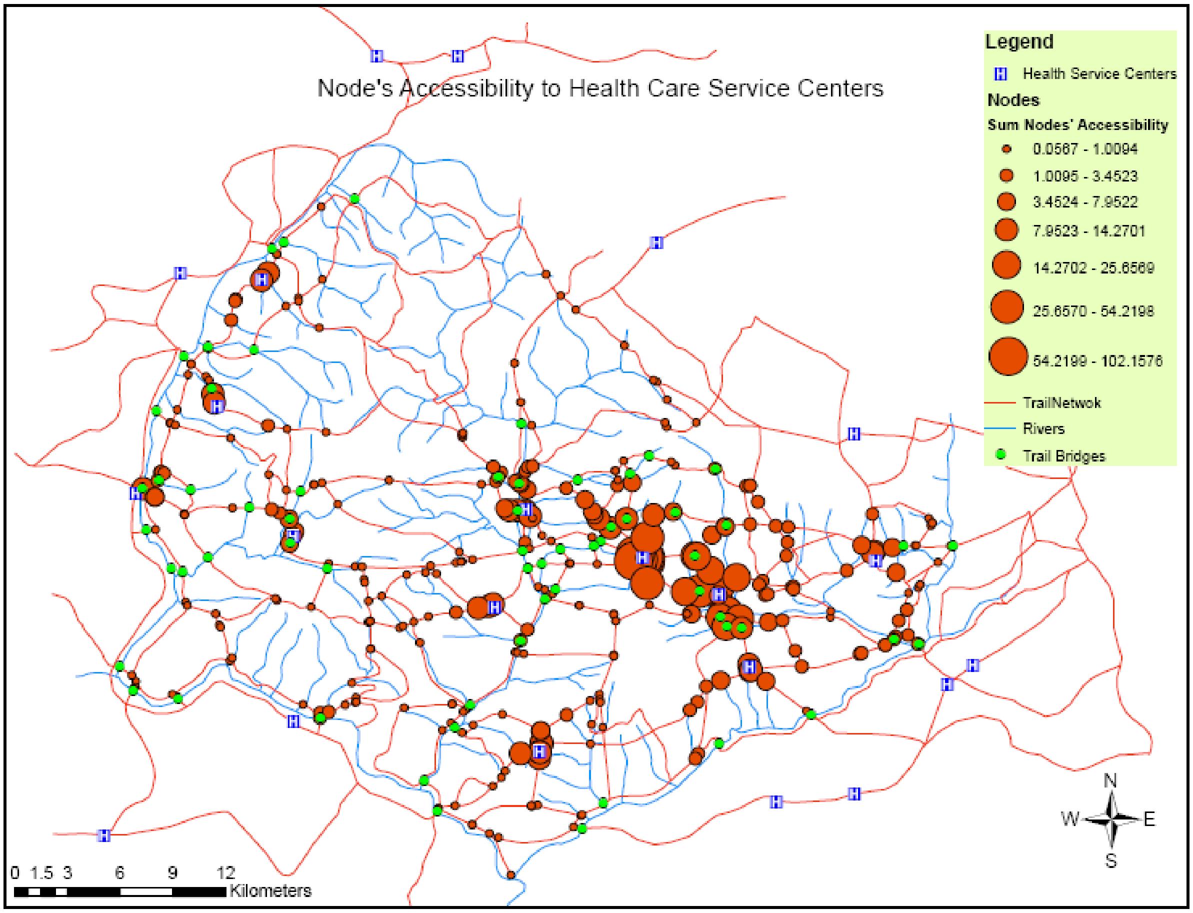


Figure 4-15 illustrates nodal accessibility to all the health care service centers. As there are impedance (barriers) at river crossing locations where there are no trail bridges, some nodes are isolated. Hence, these isolated nodes have null accessibility values. Figure 4-15 shows that many nodes in the northwest part of the district are isolated and are inaccessible to service centers. Out of 458 nodes located inside the district, 368 nodes have accessibility values and 90 nodes are isolated. Also, nodes located in the southwest part of the district have very low accessibility values. This indicates that people in these nodes are required to make longer trips to access the health care service facilities. These areas with low accessibility values are of concern.

Table 4.7: Comparison of nodal accessibility values

Scenario # 2				Scenario # 1		
SUM_ACCESS	# of nodes	%		SUM_ACCESS	# of nodes	%
> 75	6	1.63		> 75	7	1.53
50-75	3	0.82		50-75	4	0.87
25-49	5	1.36		25-49	5	1.09
10-24	34	9.24		10-24	44	9.61
5-9	20	5.43		5-9	40	8.73
1-4	**81**	**22.01**		**1-4**	**229**	**50.00**
<1	**219**	**59.51**		**<1**	**129**	**28.17**
Total	368	100.00		Total	458	100.00

Table 4.7 provides a comparison of nodal accessibility at varying SUM_ACCESS values for scenarios # 1 and # 2. These two scenarios follow similar pattern in terms of percent of nodes with SUM_ACCESS > 24. However, in scenario # 2 the percent of nodes with SUM_ACCESS < 1 is as high as 60 percent which indicates poor accessibility compared to scenario # 1. Also, 20 percent of nodes are isolated in scenario # 2.

4.2.2.2 Schools

Modeling for access to schools followed the same steps as for health care service centers. Again, the school aged population for each village is estimated to be 40 percent of the village polygon's population.

4.3 Interaction and Accessibility, and Trail Bridges Constructed in Recent Years

The trail bridge statistics show the record of trail bridges constructed in the district since 1908 (Trail Bridge Section, 2005). Out of the total 61 bridges constructed in the district up to the year 2005, 22 bridges were constructed in the years 2003-2005. An analysis of people's interaction with the health care service centers and the spatial distribution of these recently completed bridges are presented in Figure 4-16. The spatial distribution of these recently completed bridges indicates the concentration of these additional bridges around the district headquarters and also in the areas where there are relatively high interactions (trips). These bridges contribute to increase interactions and consequently increase numbers of trips to health care service centers in these areas rather than contributing to increased interactions further outside the district headquarters and in poorly served areas.

Likewise, an analysis of nodes' accessibility with respect to the health care service centers and the spatial distribution of the recently completed bridges (2003-2005) are presented in Figure 4-17. The addition of these 22 bridges in the years 2003-2005 obviously increased the accessibility indices of nodes that are located primarily in close proximity of district headquarters. However, as these recently completed bridges are concentrated in the areas with relatively high accessibility indices, the addition of these bridges does not contribute to nodes' accessibility in poorly served areas that are further away from the district headquarters, especially in the northwest part of the district.

In the case of continuation of the existing planning practices of trail bridges in the district, the above circumstances indicate that the poorly served areas, especially in northwest part of the district, are not likely to be a top priority in allocation of the future new bridges. In order to optimize the utilization of available resources and fairly distribute new additional bridges, the poorly served areas as indicated in the spatial analysis (Figure 4-16 and Figure 4-17) should be considered in the first instance. The next section discusses optimization of additional new bridges.

Figure 4-16: People's interaction with the health care service centers and the distribution of bridges constructed in past three years

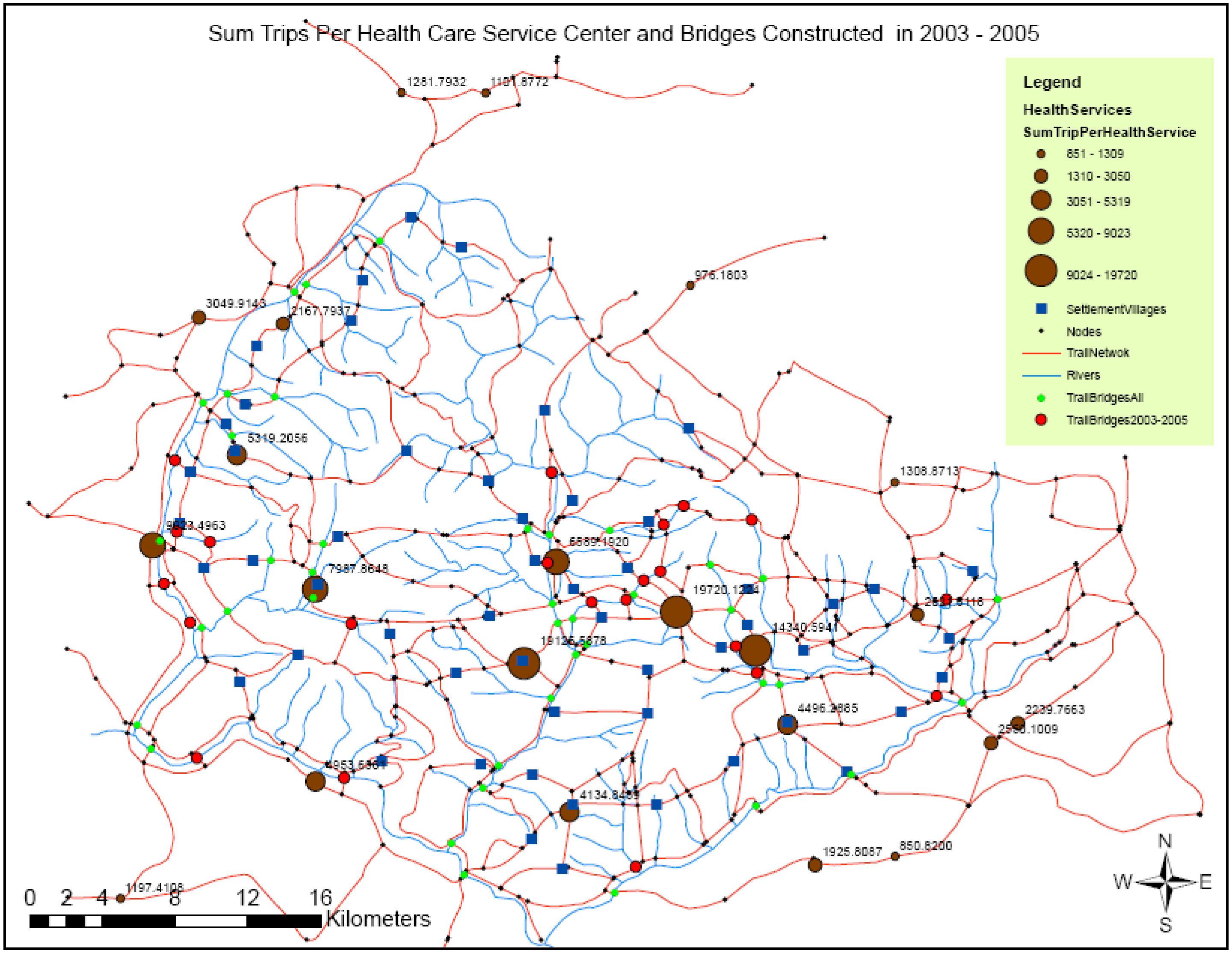
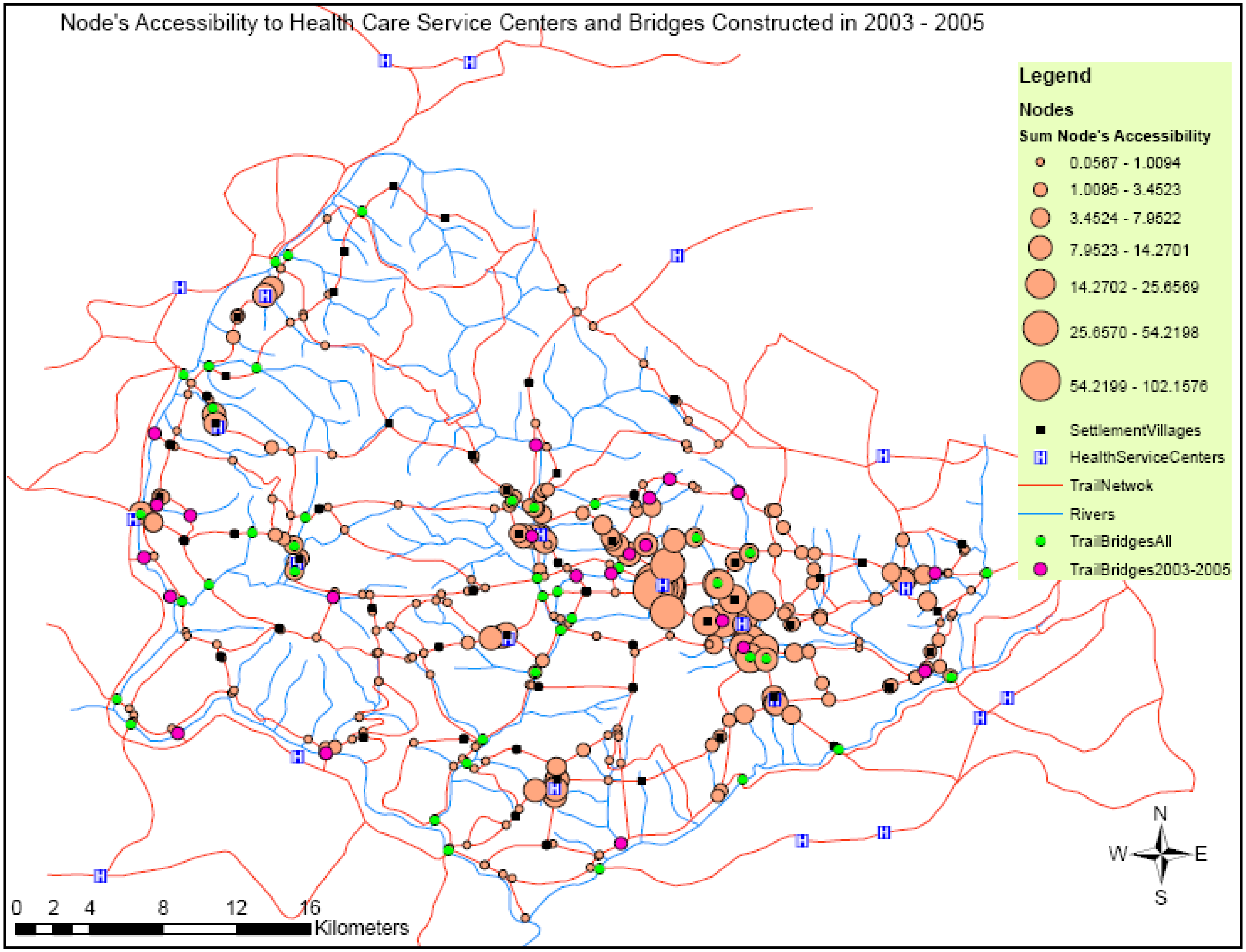


Figure 4-17: Node's accessibility and the distribution of bridges constructed in past three years



4.4 Allocation of Additional New Trail Bridges

The results of the spatial interaction and accessibility analysis clearly show the varying accessibility conditions across the district. Village settlements located in close proximity to the district headquarters are relatively more accessible to the service centers. It can be observed that the service centers are relatively closely located in the surrounding area of the district headquarters and also trail bridges are available over most of the river crossings in these areas. These conditions ease people's trips to service centers and improve accessibility. On the other hand, service centers are sparsely distributed in the areas farther away from the district headquarters and also there is a lack of trail bridges over river crossings to access these services. Often trips to service centers are obstructed and difficult to complete. There is a need for additional new trail bridges in the poorly served areas in order to reduce the accessibility gap across the district and improve overall accessibility to social services.

Decisions about the allocation of additional new trail bridges is to be made with priority to the poorly served areas as indicated by low accessibility values and isolated polygon nodes. As all the river crossings that are located in the poorly served or isolated areas cannot built in any single year, these crossing locations should be prioritized on the basis of the total number of trips over each potential trail bridge when each bridge is added to the trail network. The river crossings that generate comparatively higher number of trips are potentially important and need to be addressed in the first instances in the trail bridge planning decision-making process.

The ArcGIS Network Analyst extension can be used to estimate the number of trips over each potential trail bridge. Bridge prioritization with respect to health care service centers and schools are analyzed and the summary tables of the results of analysis are presented in the Appendix G. The tables G-1 and G-2 in the Appendix G summarize the total number of trips (Field Name: Trips_All) over each node in the case when bridges are in place and the number of trips (Field Name: Trips) when each bridge is added in the trail network respectively for health care service centers and schools. The nodes with the highest number of trips should be the top priority for allocation of new bridges. The one exception occurs when a higher tier bridge has more trips than a lower tier bridge but needs the lower tier bridge to be in place for the trips to be possible in the network. In this case, the PrevNode field is useful to identify one or more nodes that need to be in place in the network. The node identified by the PrevNode value should always be higher priority unless it is an existing bridge (Nodetype = 2).

The summary of prioritized bridge sites, based on the number of trips generated when each bridge is added to the trail network, is different for health care than schools. It is obvious because of the spatial distribution of the location of these service centers and total population. However, in both cases, the results on the number of trips over the potential new bridges indicate outward expansion from the cluster of existing bridges in the rail network. Figure 4-18 and Figure 4-19 present the distribution of the top 20 prioritized new bridges, for instance, with respect to health care service centers and schools respectively. The results of the spatial analysis provide information to the decision maker to compare options for prioritizing new bridges depending upon the purpose of the link to the particular service center.

Figure 4-18: Distribution of top 20 prioritized new bridges with respect to health care service centers

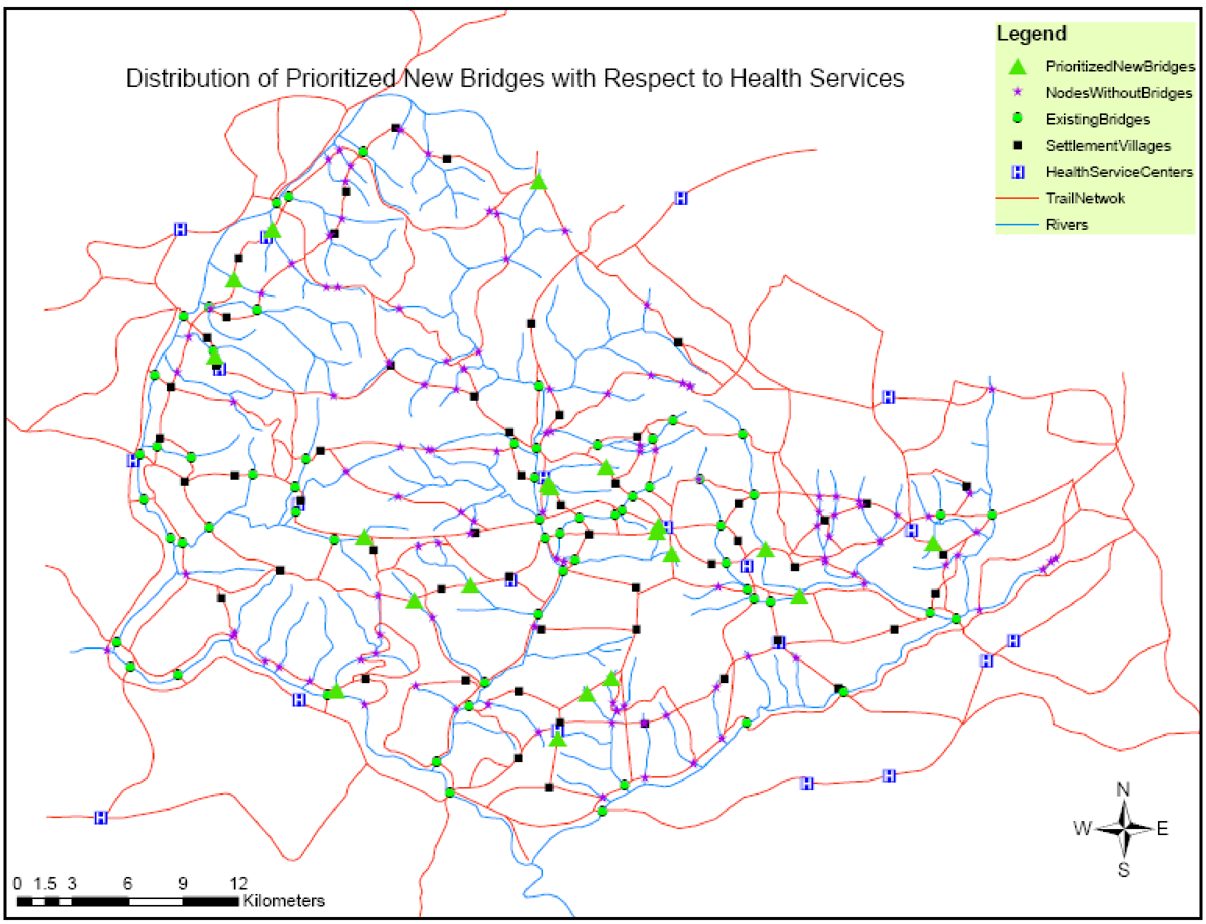
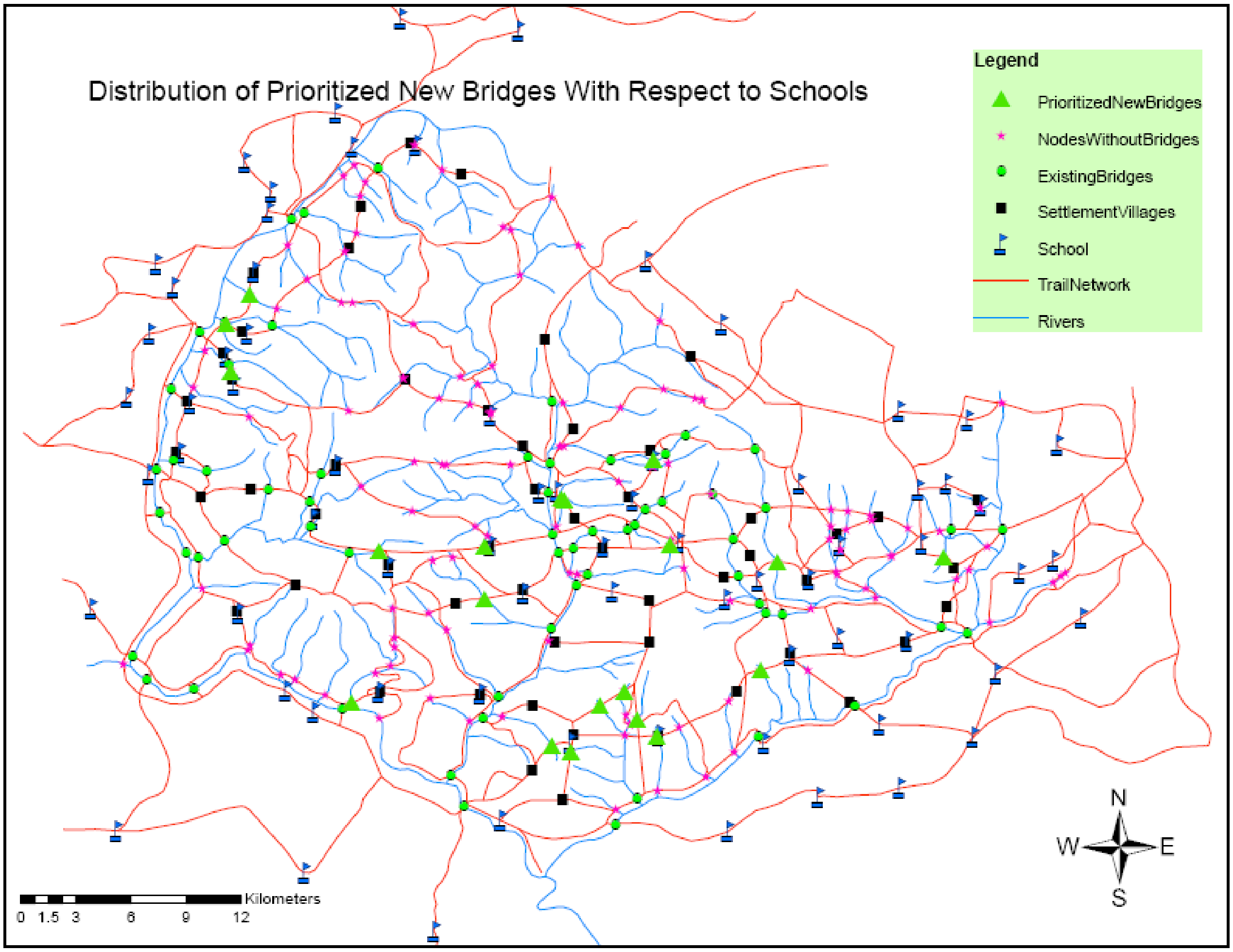


Figure 4-19: Distribution of top 20 prioritized new bridges with respect to schools



Chapter 5
DISCUSSION AND CONCLUSIONS

5.1 Summary

Improved geographical accessibility to basic social service facilities for rural populations is a goal of most governments in developing countries. Rural people in developing countries face several accessibility restrictions when trying to fulfill their needs. Development of trail-based transport systems is a key way to improve rural accessibility in rugged terrain where foot trails criss-cross with numerous rivers. The present research is focused on Nepal, a developing country with serious rural accessibility challenges and a very challenging physical environment. It reviewed the existing accessibility patterns in rural areas of Nepal and analyzed various approaches for optimizing of location of additional new trail bridges to provide “best” links to the existing social service centers to improve rural accessibility.

The research findings have three important implications for decision-making processes and planning of trail bridges. First, the study identifies un-served and poorly served geographical areas and indicates their need and priority for further investment aimed at filing the gaps of accessibility. Secondly, under financial resource constraints with limited provision of additional trail bridges, this analysis provides a rational basis for making decisions on the selection of trail bridges to serve the maximum numbers of people and geographical areas. Thirdly, this type of analysis also identifies poorly served geographical areas with regard to the spatial distribution of the social service centers across the district.

The methods of analysis in this study are based on the concepts of gravity-based spatial interaction and accessibility models. GIS applications are used in different ways, such as in creating, acquiring, integrating spatial and attribute datasets, and spatial analysis and visualization of the output results. The results of the analysis show a fairly clear indication of problems relating to rural transport and access to social service centers among the population of rural Nepal. This is, in part, attributed to insufficient provision of social service centers and also the lack of trail bridges over many river crossing locations. Often people's trips to service centers are obstructed due to the lack of trail bridges over rivers along access trails.

Improved accessibility on trail network through the allocation of additional trail bridges at river crossing locations would certainly bring greater benefits to rural communities by providing better and safe access to social service centers. Amongst the different types of social services, health and education (school) centers are considered the most pressing services and hence are the objects of analysis. The main difference between health care service centers and educational facilities is that schools are usually very widespread across the district and serve an immediately appreciated function at least for the school age population. Health service centers are sparsely and inequitably distributed. This is another aspect of the problem of accessibility with respect to the spatial distribution of service centers which is not addressed in this thesis.

It is observed that there are two aspects of accessibility problems in the district. The first is the spatial distribution of the social service centers itself. This problem is related to the availability of the existing service centers and provision of additional service centers, which is not addressed here. The second problem is the accessibility to these existing service centers which is associated with the barriers at river crossing locations along the trail network. As there are impedance (barriers) at river crossing locations where there are no trail bridges, some nodes are isolated. Hence, these isolated nodes have null accessibility values.

The results of analysis for health care service centers show that a significant number of nodes in the northwest part of the district are isolated and are inaccessible to service centers. Out of 458 nodes located inside the district, 368 nodes have some accessibility values and 90 nodes are isolated. These 90 nodes have null accessibility values (about 20 percent of the nodes inside the district). The nodes located in the southwest part of the district have very low accessibility values. This indicates that people in these nodes are required to make longer travel trips making detours to access service facilities. These unserved and poorly served areas are of concern and their limited access to basic health services needs to be addressed while making decision on the allocation of additional new trail bridges.

Likewise, the results of analysis for school centers show that a significant number of nodes in the north-west and south-west parts of the district are isolated and are inaccessible to school centers. Out of 458 nodes located inside the district, 398 nodes have some accessibility values while 60 nodes are isolated. These nodes have null accessibility values (about 13 percent of the nodes inside the district). The analysis for both health care and school centers shows about the same geographical areas that have low accessibility values and/or no accessibility values with regard to the service centers.

5.2 Discussion and Conclusions

The accessibility and spatial interaction models are complementary in term of their insight. The accessibility analysis highlights network locations that are not well serviced by existing service centres. The spatial interaction results indicate the relative demand served by the existing service centres. The results of accessibility analysis run for the health care services and the schools produce quite similar outputs in terms of a nodes' relative accessibility to social service centers. Both cases indicate almost the same geographical areas that are poorly served or unserved. However, the relative demand satisfied by the various service centers and the trail network travel distance to service centers are different for health versus education as these parameters are dependent on a node's share of population, supply capacity (attractiveness) of the service centers and their specific locations. These parameters are different for these two types of service centers.

The estimated interactions over potential new trail bridges provide a rational basis for prioritization of river crossing locations for allocation of new trail bridges. Provision of additional new trail bridges at river crossing conditions, where there are no trail bridges, would certainly contribute to improve accessibility to the available existing social service centers. Spatial interaction also shows where the next new bridges should go based on the potential demand over river crossings when each bridge is added in the trail network. The results of interaction indicate outward expansion of new bridges from the cluster of existing bridges in the trail network where the recent bridges have gone. Bridge prioritization on trip maximization alone would confirm the approach of bridge allocation approach previously followed.

Accessibility analysis identifies unserviced areas, which shows three small unserviced areas in the north-west, south-west and south of the district. With spatial interaction approach for bridge location allocation, remote regions are still unserviced or the river crossings in these areas are still not in the top of priority list. This raises the need for a complementary approach to deal with equity.

There have been no such studies in the past on spatial interaction and potential accessibility modeling using ArcGIS with respect to river crossings and trail bridges, rural communities and social services. The methods proposed in this research can also be used in a wide variety of transportation planning applications. The present study facilitates identification of poorly served geographical areas and population, and suggests where new additional trail bridges might be best sited in order to maximize access to social services.

Trail bridge planning using GIS is a feasible alternative to conventional bridge planning in the mountainous areas of Nepal. The current planning tools using paper maps and attribute database of bridges and social services provide information to introduce GIS applications. Also, trained personnel in GIS applications and resources for acquiring computers and GIS software are becoming available. Training courses and professional support services on spatial database concepts using GIS applications are available at educational and training institutions. Collaborations with international development organizations (UNDP, DFID, SDC, CIDA, etc.) are concentrating on capacity building of practitioners and decentralization of program implementation at the district level. These international organizations are either using GIS or have indicated an interest in establishing GIS installations for district development program (DFID, 2003). The evidence in this thesis indicates that the use of GIS applications provides planners and decision makers with opportunities to enhance planning and management of infrastructure facilities which includes trail bridges and social services. The proposed method is best applied to the district level planning perspectives where results of spatial analysis can be viewed for the entire district geographical area.

Using current network, high demand for health care services is concentrated in about 45 percent of the nodes in the centre of the district. This is where health services are best and where about 55 percent of the population is located. Using the hypothetical “ideal” scenario, we see increases in demand (about 80 percent overall); especially large in a certain area. This raises questions about the need for expanded health services as well as bridge crossings.

With the present practice of the development of district development plans for 20 years and consequently drawing 5 years and annual plans for implementation, the spatial interaction need to be run periodically. The preliminary list of potential prioritized bridges can be generated for 20 years perspective plan, and then re-run interaction in every five year and every year respectively for 5 years plan and annual plan. Also, a pre-construction and post-construction study on effects of new bridges and trailside data would provide information for modifications or improvements of bridge prioritization methods in future.

It is suggested that the bottom-up planning approach cannot be completely fulfilled without complementary top-down integration (Farrington et al., 2005). This is required to achieve greater interaction of accessibility-related policy making by central government departments and local authorities, agencies and communities for implementation responsibilities (Farrington et al., 2005). Also, resource sharing commitments amongst the contributing organizations at different levels ensures some input from local interests.

As the bridges are being built by and for local communities, the current participatory approach of bridge planning at the district level can be merged with GIS based planning methods. All bridges proposed by local communities could not possibly be incorporated in the annual plan for immediate implementation due to resource constraints. Hence, the 20-year prospective plan would incorporate the bridges proposed by the communities and put them in the priority order. The priority list of the proposed bridges can be reviewed periodically in the course of preparation of 5 year and annual implementation plans. Spatial interaction and accessibility based planning methods allow decision makers to make informed choices in that they are provided with information to compare options for prioritizing new bridges depending upon the purpose of the link in the trail network.

The prioritized bridges for the annual plan need to be assessed with technical, social and environmental considerations. Technical feasibility ensures that the bridge site for construction is safe and free from any slope instability problems and fulfills other engineering parameters. Also, in selecting a suitable bridge site, care should be taken to investigate a number of probable alternative sites and then decide on the site that is likely to serve the needs of the bridges at least cost and minimum adverse environmental effects (Victor, 1980). Applications of bio-engineering techniques which combine an understanding of engineering principles with knowledge of vegetation and its interaction with soil, water and climate are becoming more effective for slope stabilization and surface water management in trail bridge construction (Freer, 1991). The social feasibility establishes community ownership and responsibility for operation and maintenance of the bridge after construction (Poudel et al., 2003).

One limitation of the research is its exclusive focus on health services and education, ignoring issues related to commerce and governance. Analysis with integration of other rural services considering the purpose and frequency of travel with the demographic profile of population would provide better understanding of the potential spatial interaction and accessibility needs of rural people. However, being the key and basic social services, health and education services were taken up for analysis in the present methods. These methods can be expanded to incorporate other related social services introducing some factors or relative weights to these social services. Also, the study indicates geographical areas that are inaccessible to existing service centers. To address this issue, it may be necessary to use some complementary approaches that integrate planning expansion of social service centers with the addition of new bridges.

5.3 Opportunities for Future Research

There are several opportunities for continued research that have arisen from this study. The analysis taken on this study was to access the existing accessibility conditions and analysis on optimization of allocation of additional new trail bridges in order to improve accessibility to the available existing social service centers. An opportunity for further research would be analyzing interaction estimating the frequency of people’s travel to service center on the basis of the demographic profile of the population and their travel needs to a variety of service centers. This would expand the understanding of accessibility needs and weigh the trips or travel distance with the effective population for particular social services and purpose of travel. Also, seasonal parameters would be introduced as some river crossing locations become accessible during dry season due to low water level or construction of temporary bridges or operation of dug-out ferry-boat. Hence, the actual requirement of trail bridges for such river crossings would be less than 12 months in a year. However, it has to be considered that there are also very high risks associated with crossing rivers over such improvised bridges.

Another opportunity for further study would be on integrating planning decision-making process on allocation of new social service centers, trail bridges and also expanding the supply capacity of the existing service centers. It would provide more insights on people's interaction and accessibility conditions. Such integrated approach would provide a variety of alternative options of siting trail bridges or service centers.

Appendix A:

Rural roads, foot trails and river crossings situation in some parts of developing countries

Figure A-1: Rural roads, foot trails and river crossings situation in some part of the developing countries

Source: http://www.nepalnews.com/

Source: Lebo and Schelling, 2001

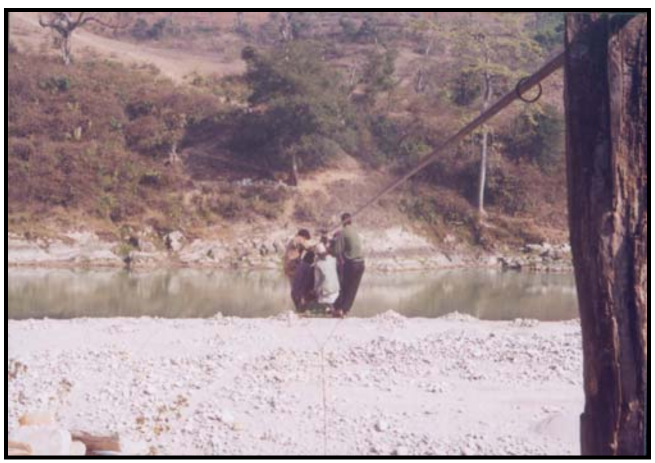
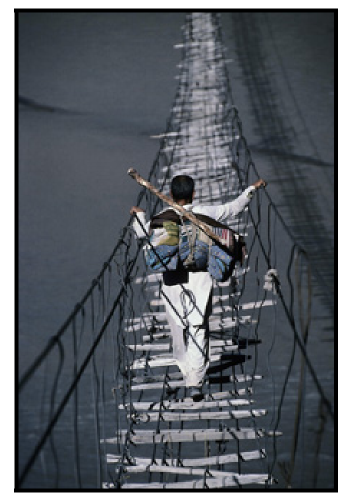


Photo: B. Devkota

Source: http://www.ekantipur.com/

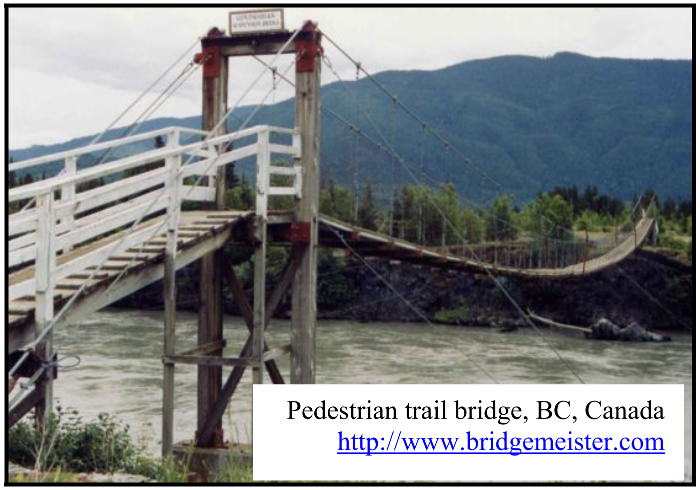


Source: http://www.roscoebridge.com/

Appendix B:

Applications of trail-suspension bridges in some selected countries of the world

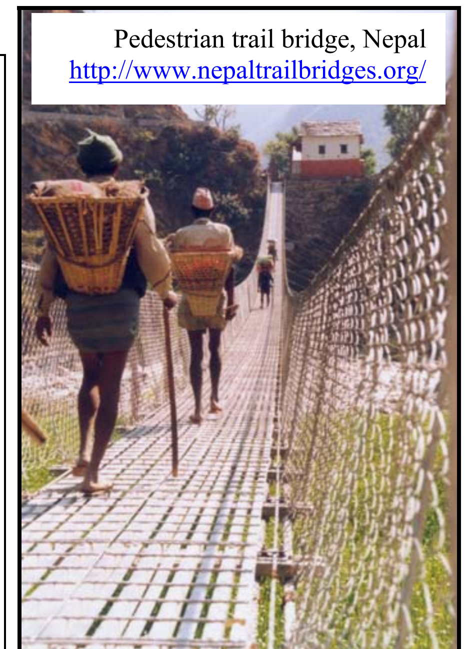
Figure B-1: A general view of some pedestrian cable supported suspension bridges for different access purposes located in various countries



Pedestrian trail bridge, BC, Canada
http://www.bridgemeister.com

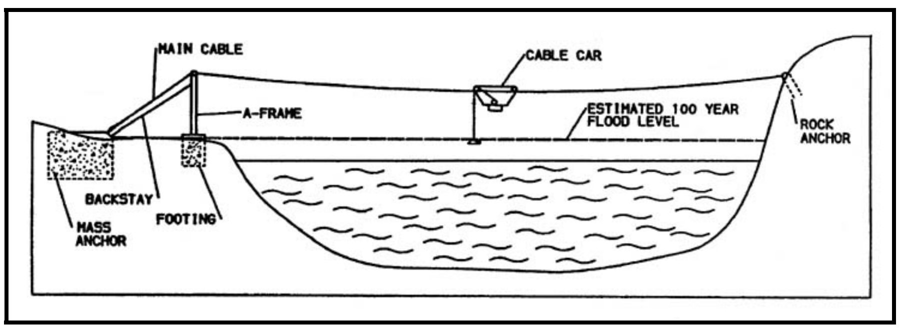
Pedestrian trail bridge, Yukon, Canada
http://www.bridgemeister.com

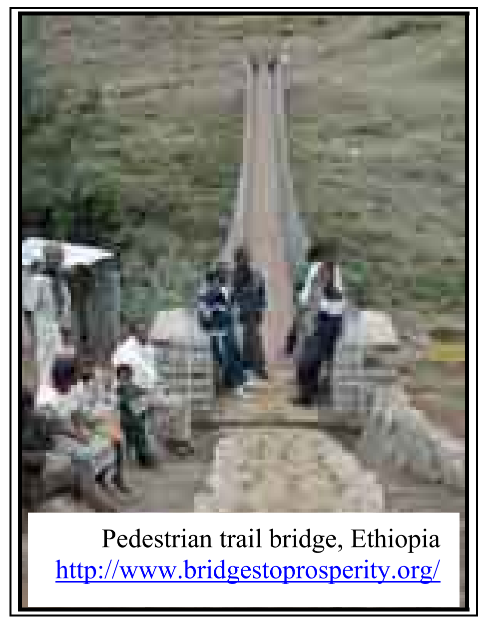
Pedestrian trail bridge, Bhutan
http://www.helvetas.org.bt/sbp.htm



Pedestrian trail bridge, Nepal
http://www.nepaltrailbridges.org/

Cable way for river discharge and water level measurement, USA
http://wwwrcamnl.wr.usgs.gov/sws/cableways/descr.htm



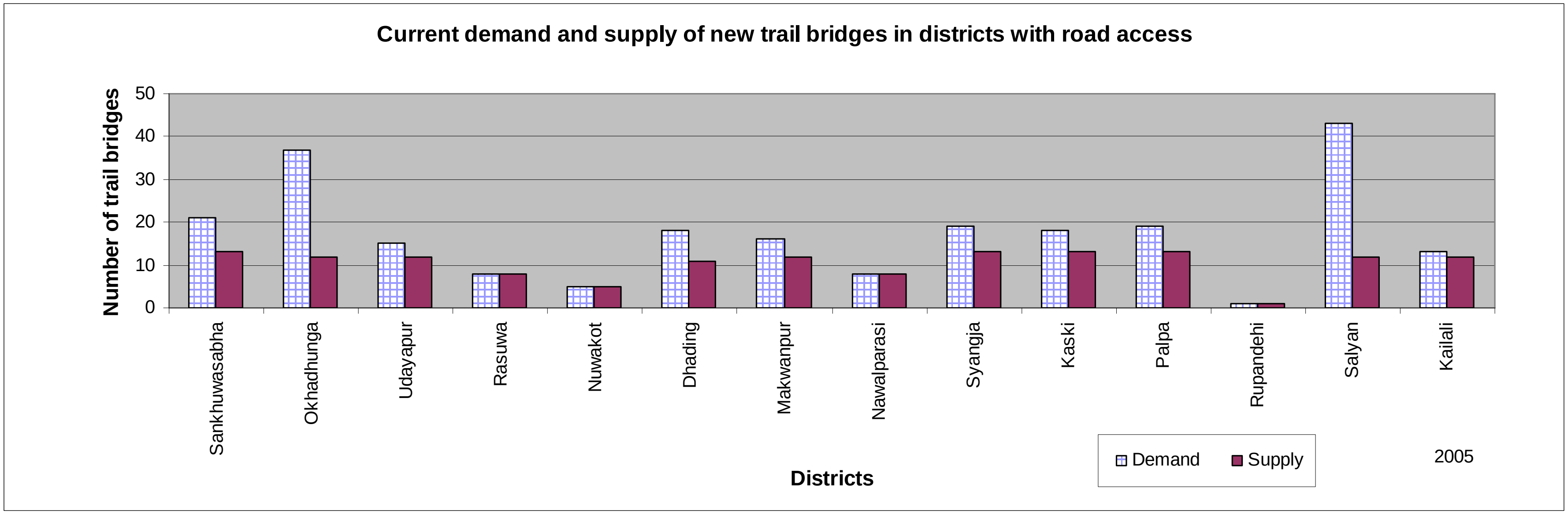


Pedestrian trail bridge, Ethiopia
http://www.bridgestoprosperity.org/

Appendix C:

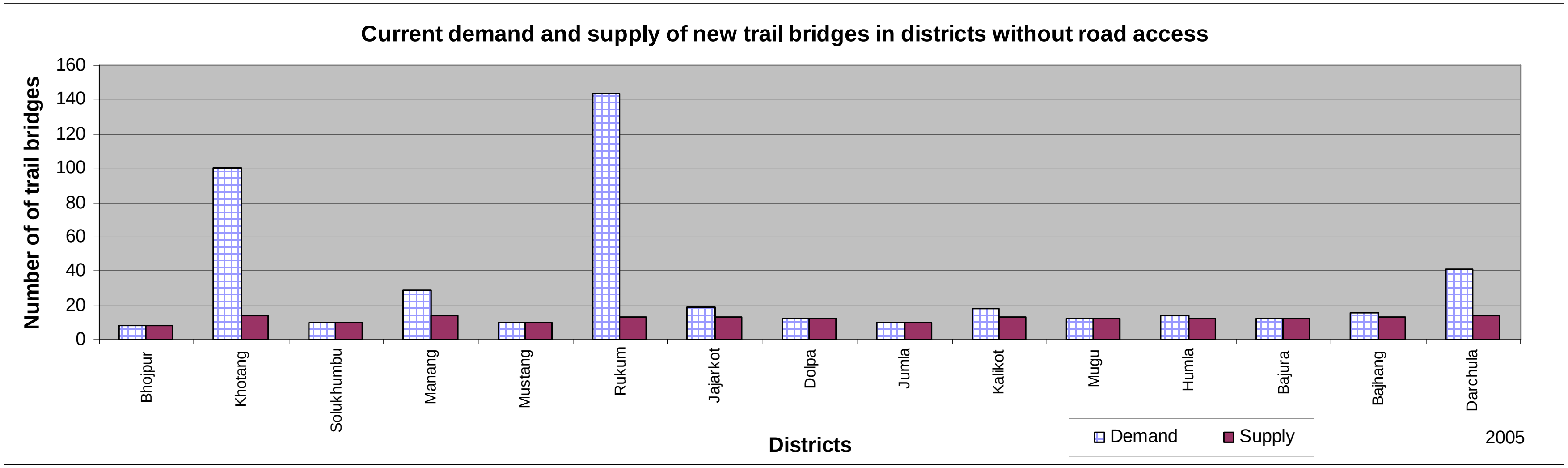
A Situation of Current Demand and Supply of Trail Bridges in Some Road Access and Without Road Access Districts in Nepal

Figure C-1: Current demand and supply of additional new trail bridges in districts with road access



Data source: Trail Bridge Section, Nepal, 2005.

Figure C-2: Current demand and supply of additional new trail bridges in districts with out road access



Data Source: Trail Bridge Section, Nepal, 2005.

Appendix D:

Data on settlement villages in the district

Table D-1: Settlement Village Data (Village Development Committee: VDC)

ID	VDC Name	VDC Area (sq km)	Max Distance from VDC center to border (km)	Population	SchoolAgePop	Pop Density (inhab./sq. km)
1	Kuibhir	13.03	3.46	2149	860	165
2	Ratmate	17.03	3.47	2540	1,016	149
3	SernaThumki	9.98	3.67	1779	712	178
4	Mamkha	26.82	9.74	3354	1,342	125
5	Rumjatar	9.05	4.73	2862	1,145	316
6	Ubu	24.80	4.61	3115	1,246	126
7	Taluwa	17.92	4.79	2094	838	117
8	Moli	16.90	4.29	3492	1,397	207
9	Jantarkhani	36.96	7.55	1399	560	38
10	Bigutar	13.07	4.17	1899	760	145
11	Bhusinga	28.22	3.82	1318	527	47
12	Rangadip	22.13	5.31	1807	723	82
13	Patale	57.29	7.70	3150	1,260	55
14	Rawadolu	17.78	4.34	1658	663	93
15	Khijikati	15.88	3.37	2499	1,000	157
16	ShreeChour	21.06	5.88	2419	968	115
17	Barnalu	14.27	6.23	2555	1,022	179
18	Madhavpur	17.80	4.12	3115	1,246	175
19	ManeBhajyang	13.45	4.18	3057	1,223	227
20	Ketuke	27.72	6.63	2569	1,028	93
21	Narayansthan	27.38	5.21	3810	1,524	139
22	Salleri	11.28	2.46	1642	657	146
23	Betini	13.74	4.34	1896	758	138
24	Baruneswar	20.35	4.63	3282	1,313	161
25	Jyamire	10.85	4.12	2375	950	219
26	Kuntadevi	8.53	2.74	2289	916	268
27	Chyanam	15.70	2.72	3039	1,216	194
28	Mulkharka	29.45	5.88	3768	1,507	128
29	Prapcha	6.21	2.45	1275	510	205
30	Harkapur	22.89	5.93	2532	1,013	111
31	Katunje	25.10	5.90	4080	1,632	163
32	Thakle	16.63	4.11	2367	947	142
33	PalapuBhanjyang	36.94	6.15	3880	1,552	105
34	Balakhu	39.06	6.04	3751	1,500	96
35	Sisneri	31.76	8.29	3588	1,435	113
36	Toksel	26.99	3.63	2156	862	80
37	Ragani	25.74	7.51	3588	1,435	139
38	Pokli	24.02	8.21	2644	1,058	110
39	Bilandu	22.58	3.71	2309	924	102
40	KeraBari	10.09	5.20	1994	798	198
41	Narmadeshwar	9.04	3.11	1631	652	180
42	Phedhiguth	19.89	3.16	3577	1,431	180
43	Phulbari	18.61	3.56	3865	1,546	208
44	Kalikadevi	19.10	5.63	1835	734	96
45	Raniban	11.83	2.87	1899	760	160
46	Singhdevi	17.13	3.35	2379	952	139
47	Yasam	14.86	6.87	1683	673	113
48	Gamnagtar	12.96	3.80	2963	1,185	229
49	Phalante	45.68	6.90	2982	1,193	65
50	KhijiChandeswar	13.33	3.14	3040	1,216	228
51	Bhadoure	11.62	2.55	2531	1,012	218
52	Thulachap	21.20	5.50	3443	1,377	162
53	Pokhare	14.70	3.45	1813	725	123
54	Diyale	11.69	3.91	2553	1,017	218
		1088.13	4.80	141,289	56,512	130
		Area of the District	Average Max Distance	Total Pop	TotalSchAgePop	PopDensityDistrict

Population data source: Central Bureau of Statistics, Nepal, 2004

Appendix E:

Output results of spatial interaction and accessibility analysis for educational facilities

Figure E-1: Sum of trips per school in scenario # 1 (all river crossing locations are accessible)

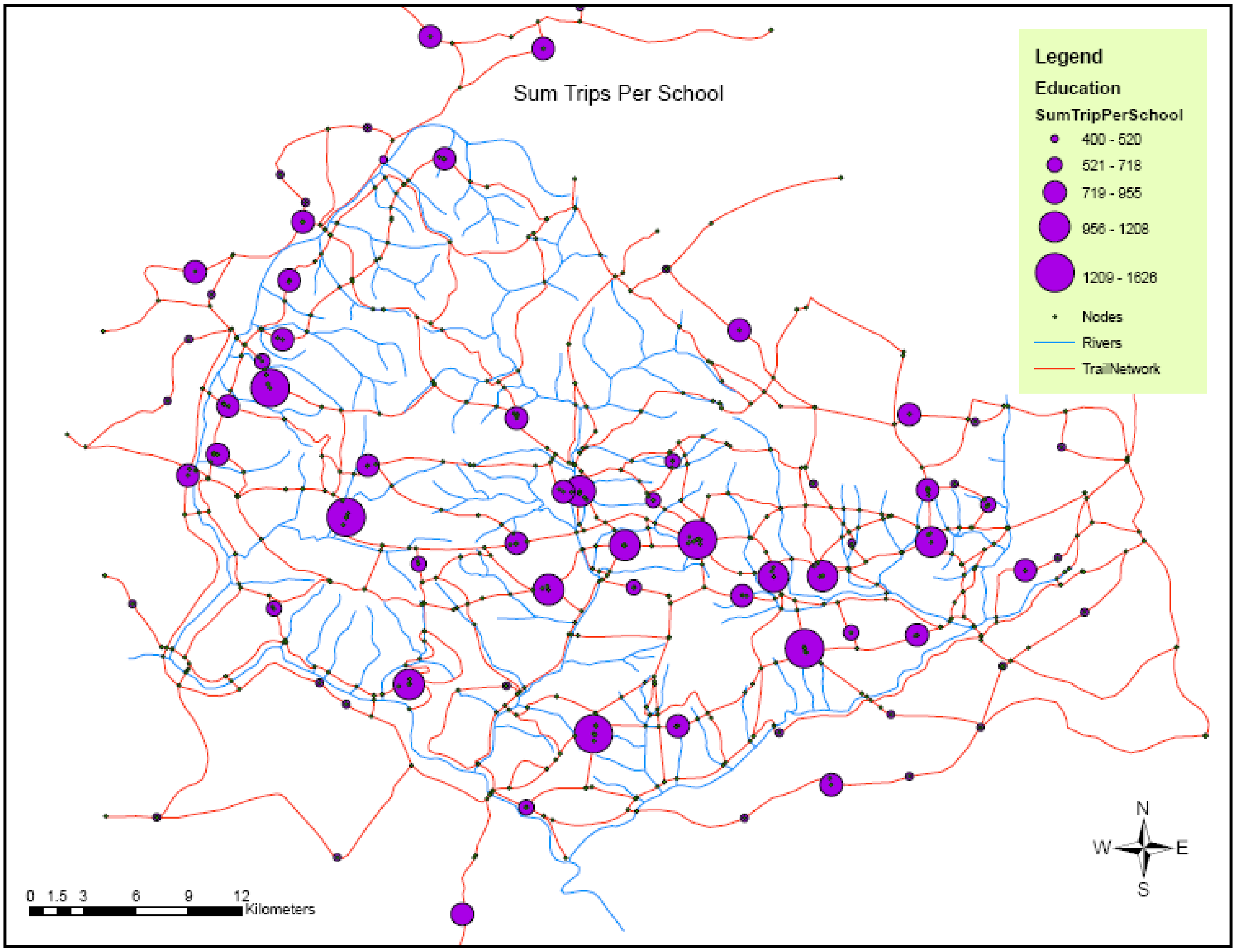


Figure E-2: Sum of travel distance per school in scenario # 1 (all river crossing locations are accessible)

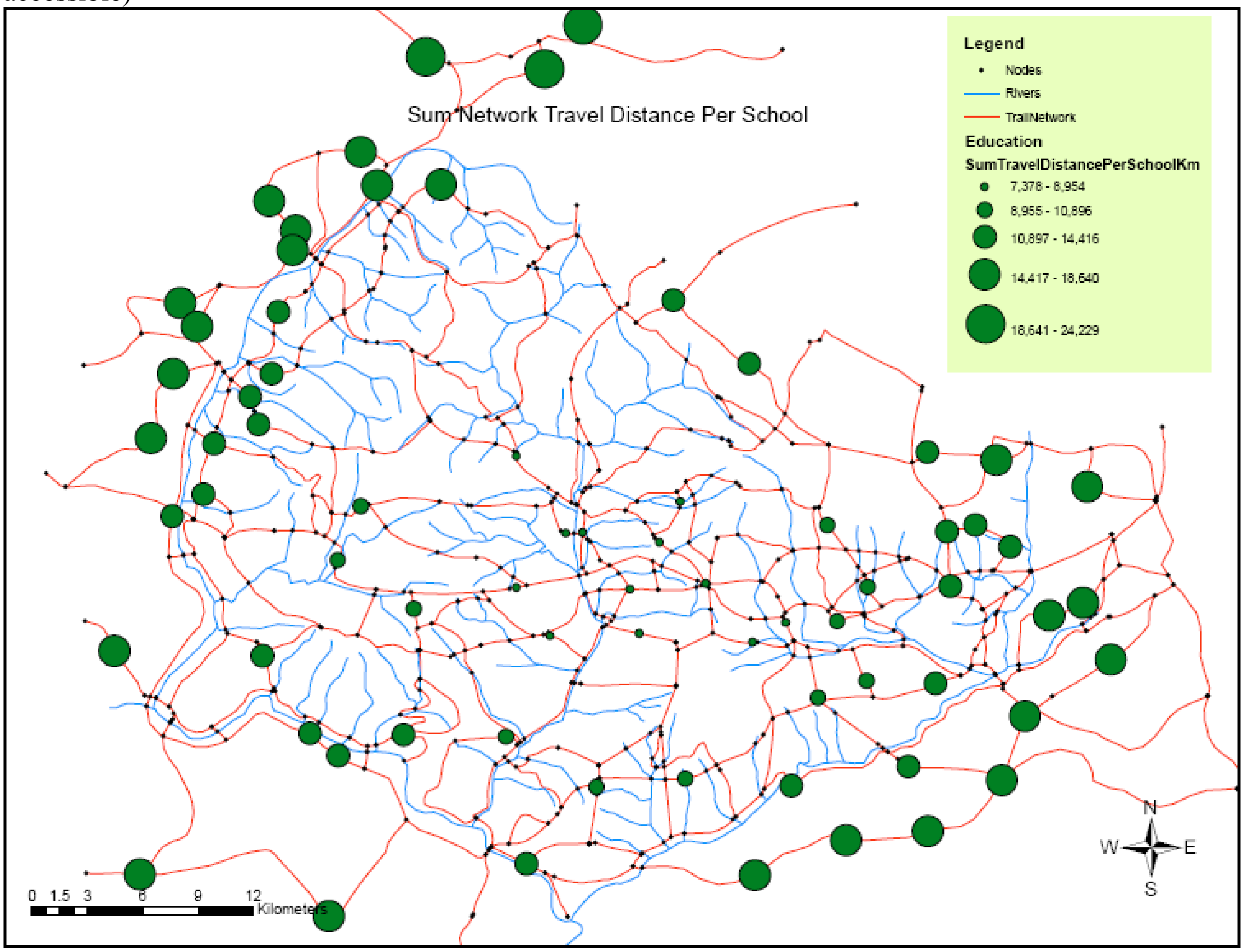


Figure E-3: Sum of trips per school in scenario # 2 (river crossing locations with out trail bridges create obstruction)

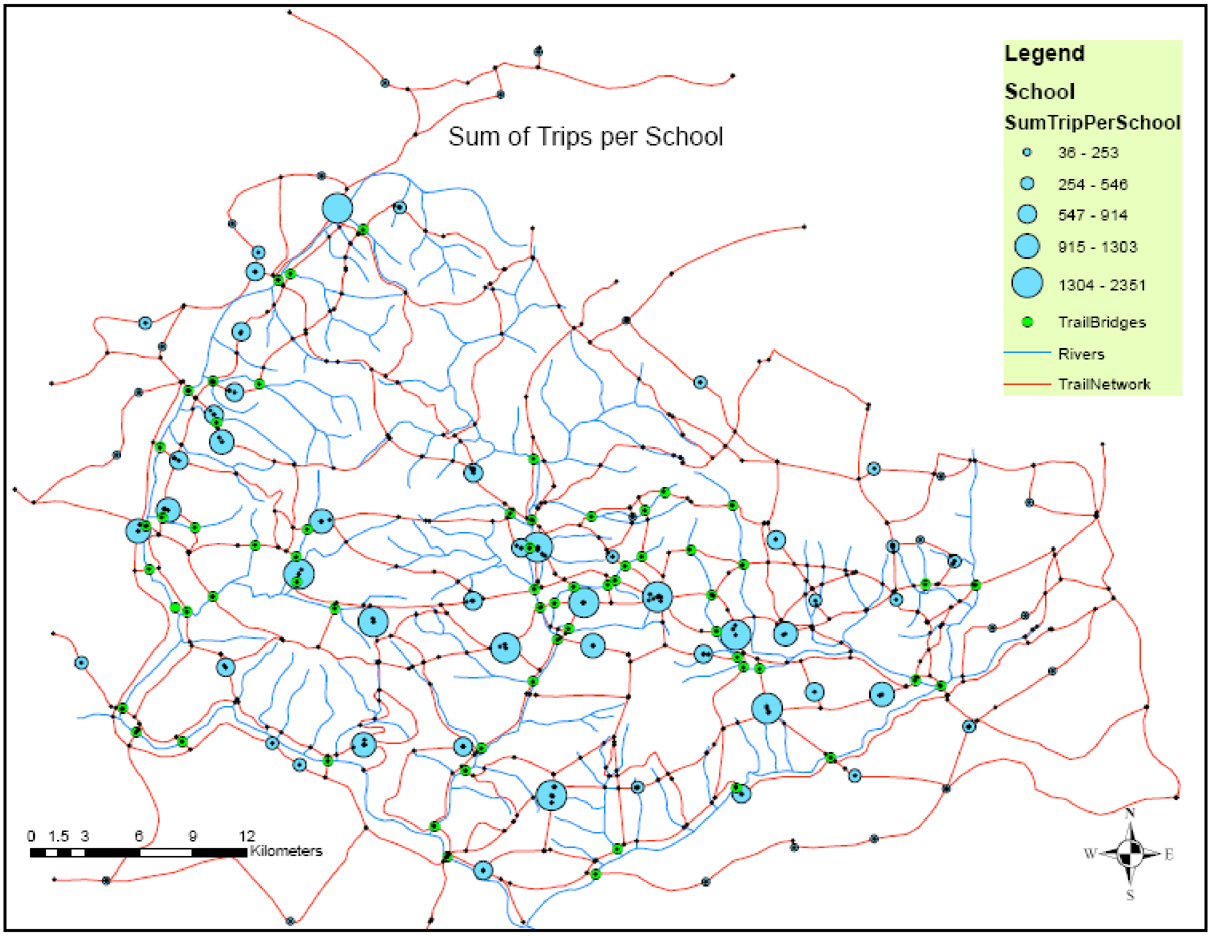


Figure E-4: Sum of network travel distance per school in scenario # 2 (river crossing locations with out trail bridges create obstruction

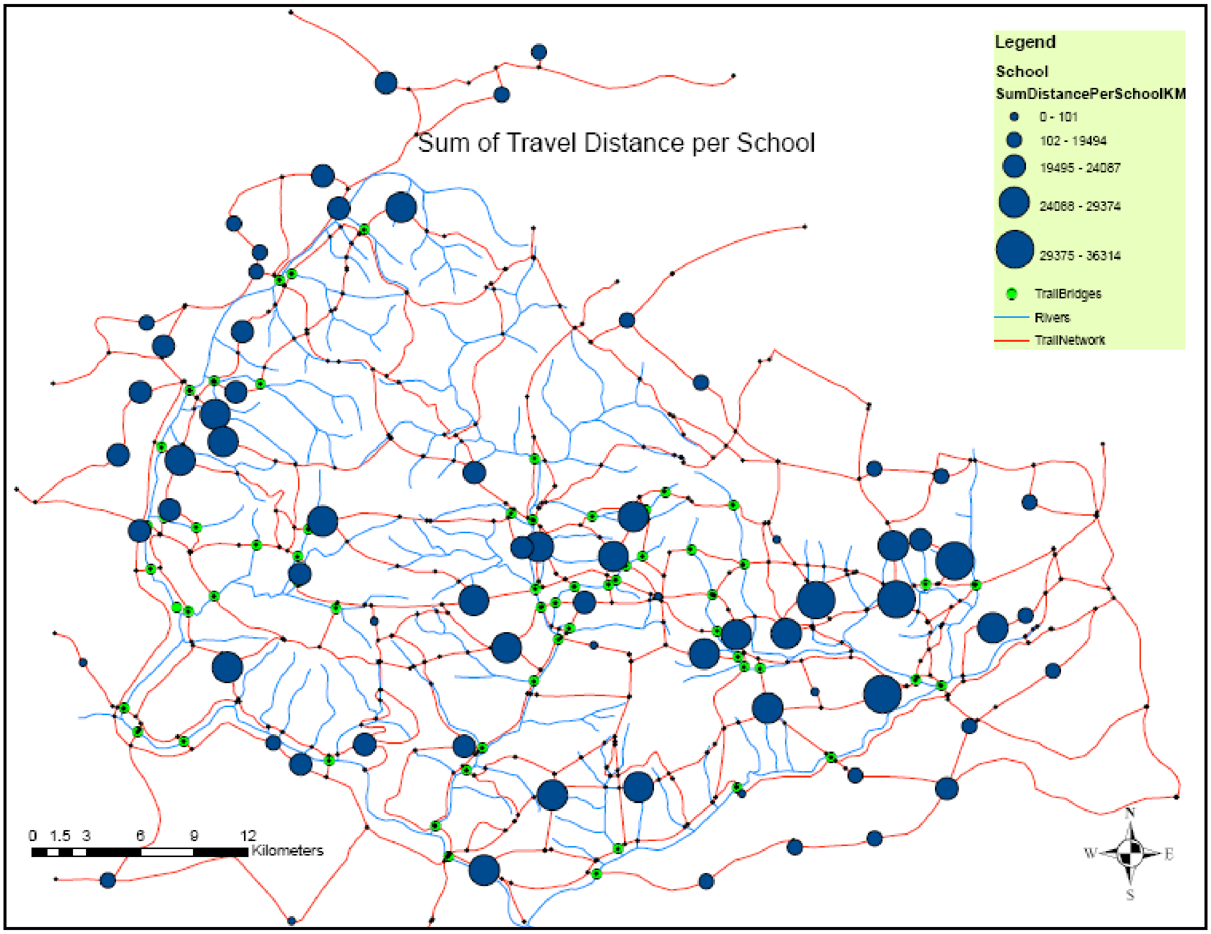


Figure E-5: Node's accessibility to all schools in scenario # 1 (all river crossing locations are accessible)

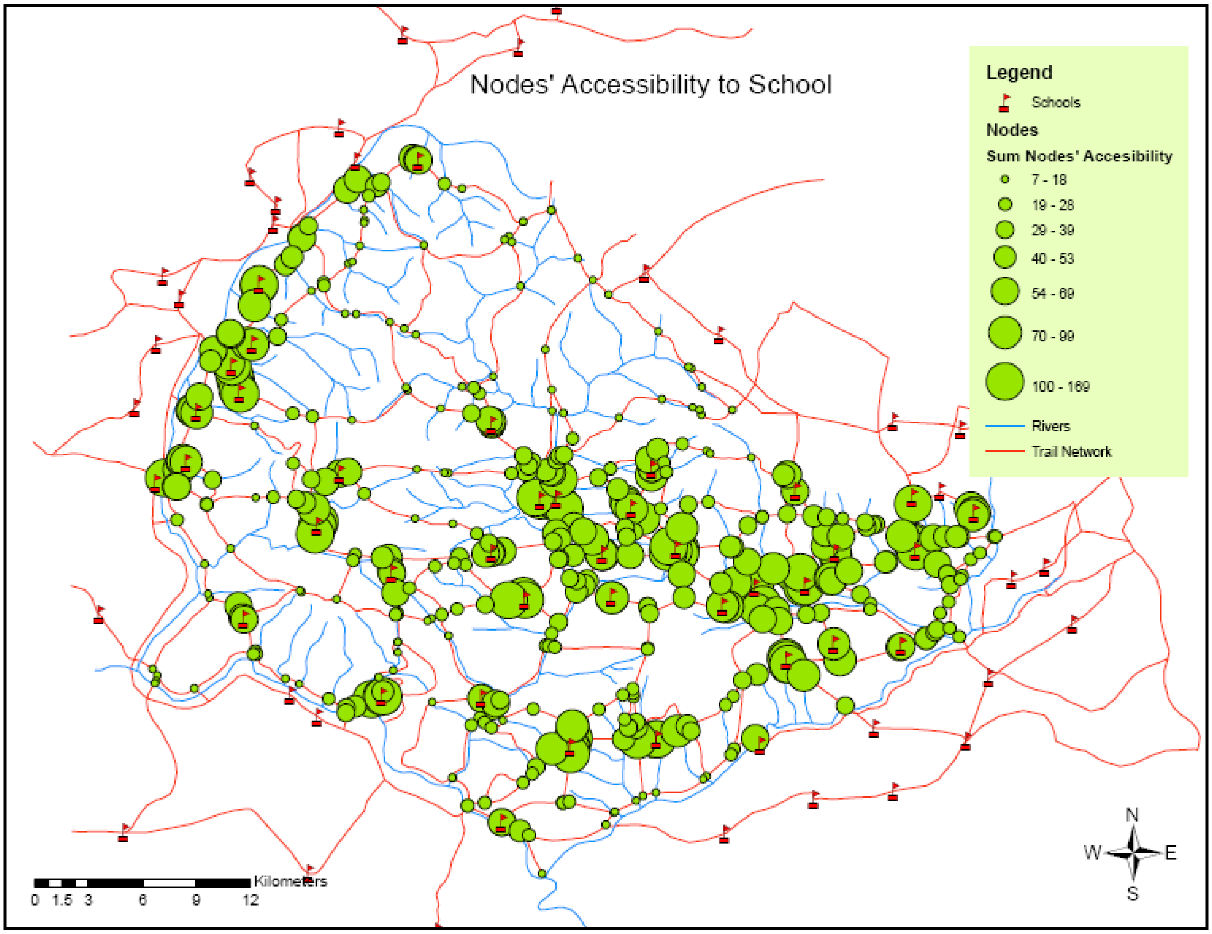


Figure E-6: Node's accessibility to all schools in scenario # 2 (river crossing locations with out trail bridges create obstruction)

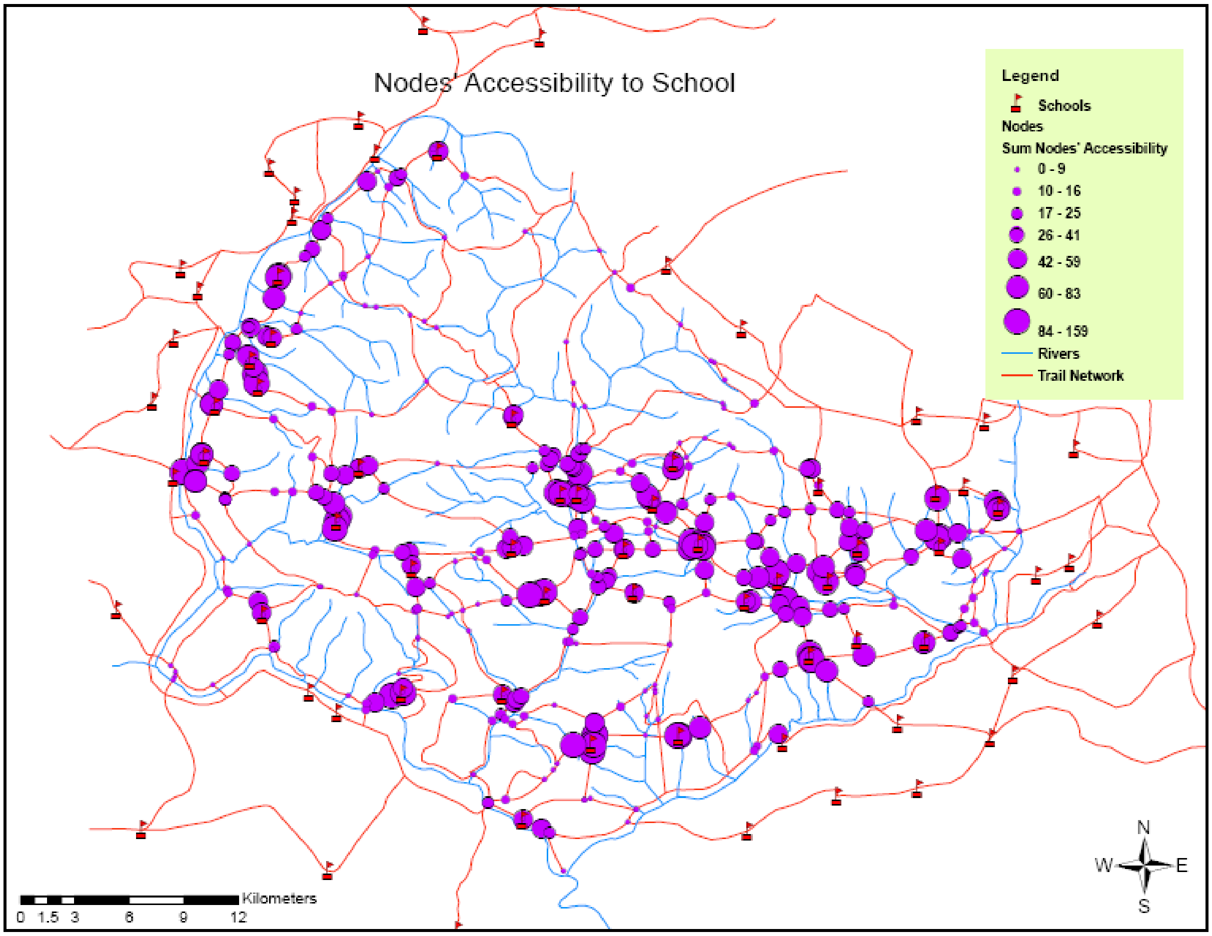


Figure E-7: People's interaction with the school centers and the distribution of bridges constructed in the past three years

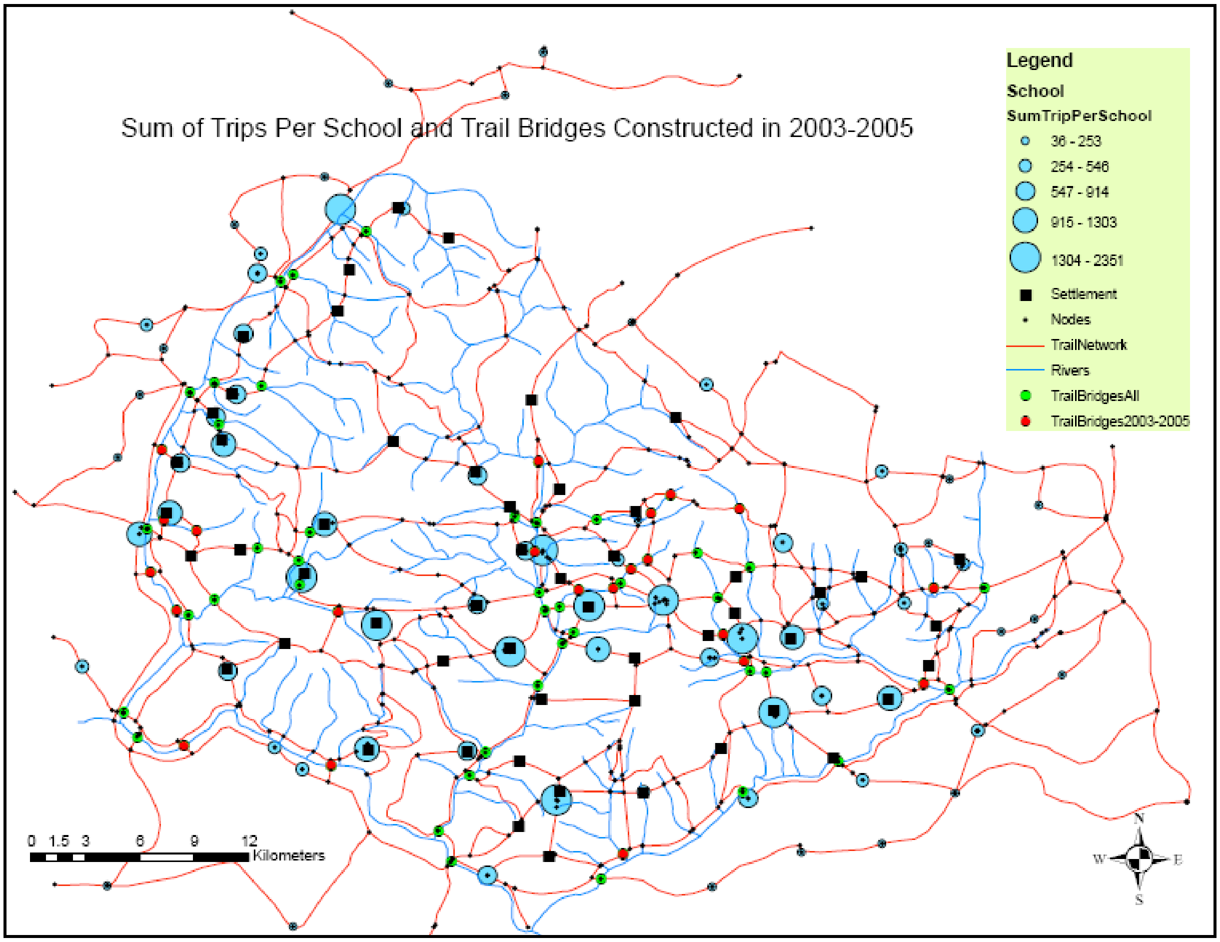
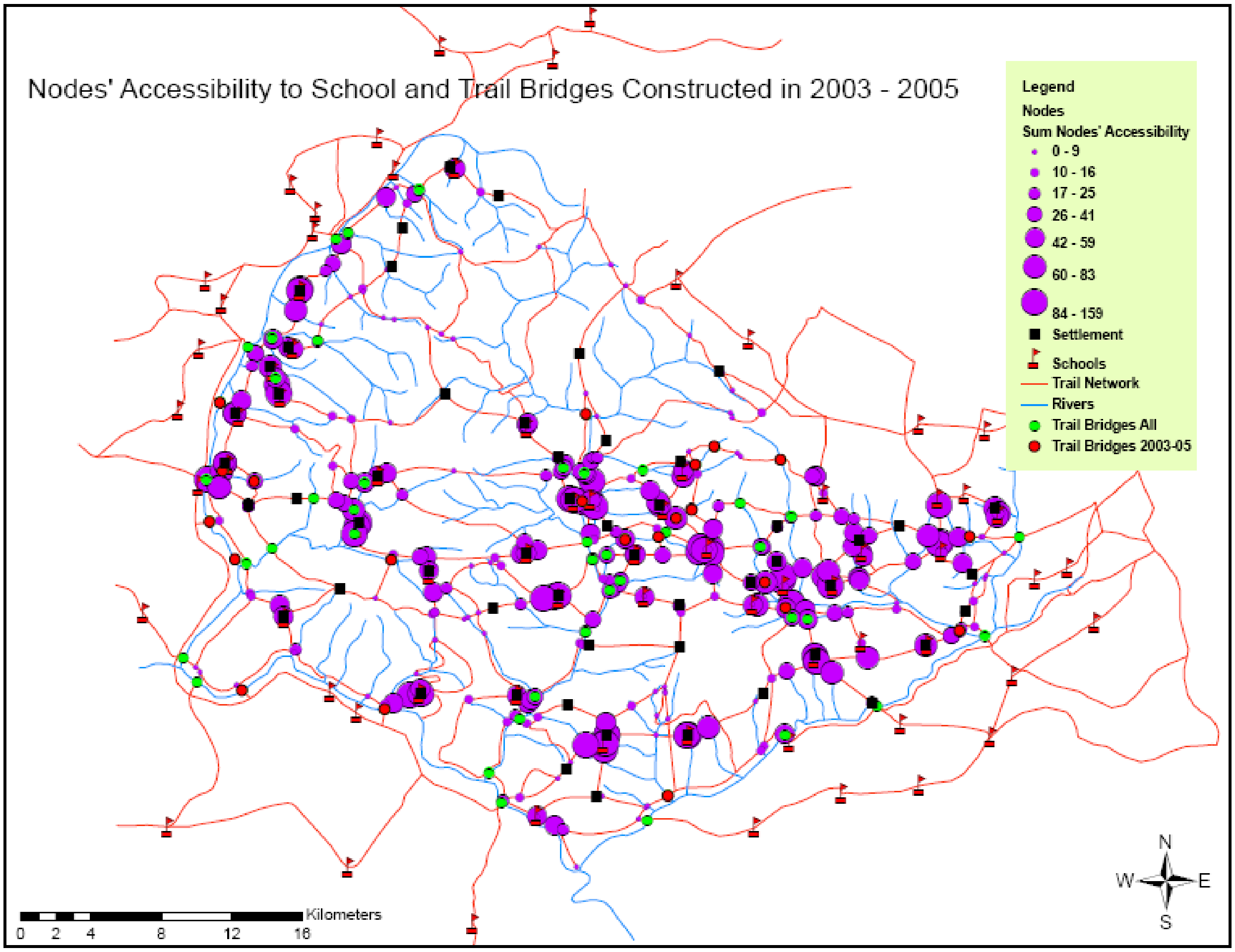


Figure E-8: Node's accessibility and the distribution of bridges constructed in the past three years



Appendix F:

Bridge Prioritization Process

Bridge Prioritization Process

The bridge prioritization process adds bridges working outwards from the endpoints of the existing route network. As each tier of new bridges is added to the network, the number of trips expected over each new bridge is calculated. Once all potential bridges have been added, the new bridges are sorted in descending order on the Trips field. This produces a preliminary prioritization of the new bridges. Each bridge in the sorted list is checked to ensure that its previous node has been given higher priority. If the previous node has lower priority, it is moved ahead of the current bridge in the priority list. The result is an outward expansion of the route network that maximizes the total number of trips as each new bridge is added to the network.

The prioritization process has been implemented as an ArcGIS custom toolbox named NA_Bridge_Tools. This tool contains script tools and models that perform the analysis. The following sections describe the sequence of processing required to create a summary table listing the new bridges in priority order. Processing tasks can be grouped into five phases: Initialization, Interaction - Full Network, Interaction - Existing Network, Network Extension, and Bridge Prioritization.

Initialization

The initialization phase calculates demand for network nodes, creates the closest facility layer and adds fields to the nodes feature class and the Facilities, Incidents and Routes sub-layers.

Node Demand

Parameters: <districts_fc> <districts_ID_field> <districts_demand_field> <nodes_fc> <nodes_ID_field>

Node Demand adds new fields named Demand, PrevNode and Tier to the nodes feature class (Nepal.mdb\TrNodes) and calculates the new demand item by allocating equal shares of district level demand to all nodes within each district and adding district level demand to the node nearest the district centroid for districts that contain no nodes (not necessary for the Nepal dataset). The PrevNode field is initialized to 0 and the Tier field is set equal to the NodeType field.

Create Closest Facility Layer

Parameters: <network_dataset> <CF_layer_name> <nodes_fc> <centers_fc>

This model creates a new Network Analyst Closest Facility Layer and loads the centers_fc points as Facilities and the nodes_fc points as Incidents. In order to view the results in ArcMap, this model must be run from within the Model Builder window. Right click on the Create Closest Facility Layer model in the NA_Bridge_Tools toolbox and choose Edit from the popup menu. Double click on output_layer_name oval and enter a name for the new closest facility layer. Close the parameter dialog and click the run entire model icon on the Model Builder toolbar. When the model finishes running, close the Model Builder Window.

Add Analysis Fields

Parameters: <CF_layer> <facilities_sublayer> <incidents_sublayer> <demand_expr> <centers> <supply_expr>

This model adds a Demand field to the Incidents sub-layer, a Supply field to the Facilities sub-layer, and adds Demand, U_Interactn and Trips fields to the Routes sub-layer. The demand expression must be [TrNodes.Demand] and the supply expression must be of the form [HealthCenters.SUPPLY] or [Schools2.SUPPLY].

Interaction Analysis - Full Network

Interaction over the full network (assuming all potential bridges have been built) is calculated by solving for routes to the three closest facilities assuming there are no barriers to movement and then calculating interaction for each route.

Solve Routes

Parameters: <nodes_fc> <barriers_expression> <CF_layer_name>

This model solves for routes with or without barriers. There is no tool to remove barriers once they have been added to the closest facility Barriers sub-layer. But barriers can be removed by adding a new set of barriers using a selection expression that ensures the new set is empty. To solve for routes assuming that all bridges are in place, i.e. there are no barriers the <barriers_expression> should be: "[Tier] < 0".

Interaction

Parameters: <routes_sublayer> <nodes_fc> <facilities_sublayer>

Interaction calculates unconstrained and production-constrained interaction based on the current set of routes.

SummarizeALL

Parameters: <workspace> <nodes_fc> <routes_sublayer> <summary_table_name>

This model creates a summary table and calculates the total number of trips over each bridge assuming that all bridges are in place.

Interaction Analysis – Existing Network

Analysis of interaction over the existing network is accomplished by solving for routes while treating potential bridges as barriers to movement and then calculating interaction for each resulting route.

Solve Routes

Parameters: <nodes_fc> <barriers_expression> <CF_layer_name>

This is the same model used above but with the <barriers_expression> changed to "[Tier] = 1" to add potential bridges to the Barriers sub-layer. The resulting routes will be based on the existing network.

Interaction

Parameters: <routes_sublayer> <nodes_fc> <facilities_sublayer> <output_routes_fc>

This model calculates the unconstrained interaction (U_Interaction) and production-constrained interaction (Trips) between origin nodes and service centers.

SummarizeTier

Parameters: <workspace> <nodes_fc> <routes_fc> <summary_table_name> <tier>

By setting Tier = 2, this model calculates the total number of trips over each existing bridge. The summary table is the output table created by SummarizeALL.

NonBridgeNodes

Parameters: <nodes_fc> <trails_fd> <routes_sublayer>

This model calculates the Tier field for non-bridge nodes. Tier = 2 for non-bridge nodes that intersect existing routes. Tier = 1 for non-bridge nodes that do not intersect existing routes. Tier = 1 nodes are treaated the same as potential bridges when extending the network.

Network Extension

The following sequence of models and script tools must be executed repeatedly until all potential bridges have been added to the network. The first time through this loop, Tier = 3 (existing bridges are treated as Tier 2). For each subsequent iteration, Tier is incremented by 1. The current tier number is used as an argument to New Bridges and Summarize Tier and the <selection_expression> in Update Nodes must be modified each time to replace the old tier number with the current tier number at the end of the expression.

New Bridges

Parameters: <TrailsFD> <trails_fc> <nodes_fc> <routes_sublayer> <Tier>

This model creates a new feature class called tmpNewBridges containing the next tier of bridges to be added to the network and stores the identifier of the previous node for each new node added to the network. The previous node is the endpoint of the route that will be extended by adding the new node.

Update Nodes

Parameters: <tmpNewBirdges_fc> <nodes_fc> <routes> <selection_expression>

This model adds potential bridges that intersect existing routes to the network by updating the Tier field for nodes identified as new bridges. The selection expression and [tmpNewBridges.Tier] = 3. The expression must be edited each time the tool is run to replace the 3 with the current tier number.

Solve Routes

Parameters: <nodes_fc> <barrier_expression> <CF_layer_name>

This is the same model used above but with the <barrier_expression> changed to "[Tier] = 1" to add potential bridges to the Barriers sub-layer. The resulting routes will be based on the extended network.

Interaction

Parameters: <routes_sublayer> <nodes_fc> <facilities_sublayer> <output_routes_fc>

This model calculates the unconstrained interaction (U_Interaction) and production-constrained interaction (Trips) between origin nodes and service centers.

SummarizeTier

Parameters: <workspace> <nodes_fc> <routes_fc> <summary_table_name> <tier>

This model calculates the total number of trips over each new bridge in the current tier. Repeat the sequence of network extension processes until all potential bridges have been added to the network.

Prioritization

The prioritization script is the final step in the process and is run only after all potential bridges have been added to the network.

Prioritize

Parameters: <workspace> <input_summary_table> <output_prioitized_table_name>

This script sorts the summary table into priority order. Nodes are sorted in ascending order by Tier. Nodes in Tier 3 or higher are then sorted in descending order by Trips. This is a first approximation to priority order. The final step is to check the PrevNode for each added node. If the PrevNode node is lower priority than the current node, it is moved ahead of the current node in the list.

Appendix G:

Output results of spatial analysis on prioritization of new bridges

Table G-1: Summary of trips over bridges on the trail network with respect to health care service centers

NodeNum	NodeType	Trips_ALL	Trips	PrevNode	Tier
329	1	7530	7530	327	3
217	2	5748	6634	0	2
269	2	3299	6510	0	2
270	2	3299	6510	0	2
349	2	1819	5641	0	2
398	2	2868	5415	0	2
369	1	5566	5404	334	3
112	1	6112	5120	110	3
342	2	2036	5081	0	2
319	2	4173	5005	0	2
263	2	4930	4719	0	2
52	1	9194	4624	46	3
451	2	3564	4527	0	2
415	1	4233	4163	412	3
454	2	3407	4118	0	2
317	1	4421	3712	292	3
520	2	1676	3638	0	2
226	1	4566	3635	215	3
361	1	3944	3285	371	3
597	2	564	3192	0	2
296	2	4058	3176	0	2
541	2	976	3009	0	2
574	1	2866	2972	568	3
443	2	2778	2935	0	2
201	2	5962	2908	0	2
386	2	2917	2671	0	2
449	2	2139	2558	0	2
260	1	2938	2528	284	3
356	1	2441	2490	328	3
197	2	2229	2488	0	2
257	1	2884	2475	247	3
440	2	3496	2386	0	2
43	2	1217	2340	0	2
232	2	1969	2321	0	2
439	1	2369	2299	434	3
605	2	303	2297	0	2
307	2	1047	2276	0	2
350	2	1670	2245	0	2
527	1	2201	2152	519	3
509	1	1901	2136	505	3
531	1	1880	2114	544	3
75	1	2095	2104	69	3
345	1	2123	2090	340	3
435	1	2011	2013	428	3
32	1	1665	1948	54	4
94	2	637	1936	0	2
569	1	1887	1931	567	3
175	2	436	1910	0	2
388	1	1765	1814	413	3
557	1	1747	1747	556	4
457	2	1008	1723	0	2
242	2	2777	1706	0	2
502	1	1686	1686	518	4
16	1	1679	1679	17	6
491	1	2353	1648	486	3
294	1	2118	1639	247	3
306	1	1596	1596	301	3
89	1	2735	1571	87	3
322	2	972	1523	0	2
497	1	1466	1466	473	4

NodeNum	NodeType	Trips_ALL	Trips	PrevNode	Tier
81	1	1361	1437	71	4
553	1	1412	1412	543	4
221	2	2478	1385	0	2
335	1	1655	1370	331	3
401	1	1276	1369	357	3
312	2	3157	1360	0	2
166	2	455	1292	0	2
105	1	1261	1286	102	3
560	1	1273	1273	562	4
57	1	2360	1216	66	3
48	1	585	1207	45	5
524	1	1868	1162	511	3
20	1	3921	1136	27	4
49	1	823	1131	45	5
126	1	1100	1125	136	3
154	1	1481	1103	150	3
51	1	1144	1062	56	4
303	2	391	1040	0	2
70	1	732	1040	111	5
173	1	1025	1025	179	3
355	1	1014	1014	358	3
492	1	1013	1013	485	3
80	1	941	994	78	4
200	1	970	970	185	3
461	1	955	964	460	3
193	2	287	932	0	2
157	2	3467	880	0	2
470	1	1192	873	441	3
507	2	723	863	0	2
139	2	1077	830	0	2
23	1	957	829	26	5
437	1	811	811	433	3
489	1	805	805	472	4
474	1	298	798	504	3
540	1	633	797	514	3
211	1	766	766	245	3
379	2	3762	762	0	2
575	1	1413	756	573	3
128	1	723	723	152	5
272	2	5984	719	0	2
421	1	687	687	420	3
305	2	229	687	0	2
532	2	4795	682	0	2
295	1	999	680	314	4
267	1	667	667	265	3
297	1	1000	667	315	3
132	1	742	664	121	4
318	1	1167	656	364	3
581	1	642	642	578	4
354	1	640	640	352	4
192	1	625	625	176	3
299	1	599	599	310	4
287	1	592	592	282	4
229	1	586	586	273	6
116	1	584	584	82	5
599	1	523	569	600	3
503	2	336	556	0	2
90	1	528	528	83	5
530	2	34	524	0	2
293	1	617	490	268	3
Contd…					

Table G-2: Summary of trips over bridges on the trail network with respect to schools

NodeNum	NodeType	Trips_ALL	Trips	PrevNode	Tier
263	2	1,835	2,152	0	2
221	2	1,509	1,524	0	2
560	1	2,243	1,455	559	3
557	1	1,372	1,372	556	4
112	1	1,286	1,342	110	3
345	1	1,108	1,108	340	3
574	1	911	1,068	568	3
296	2	1,256	1,061	0	2
89	1	1,036	1,036	87	3
379	2	438	1,020	0	2
443	2	723	951	0	2
217	2	824	945	0	2
43	2	2,160	936	0	2
449	2	720	923	0	2
257	1	921	921	247	3
491	1	808	901	486	3
335	1	901	901	331	3
201	2	982	879	0	2
260	1	872	872	284	3
540	1	319	841	514	3
16	1	820	820	17	6
242	2	1,295	811	0	2
342	2	397	782	0	2
32	1	468	779	54	4
23	1	857	779	26	5
197	2	676	777	0	2
553	1	774	774	543	4
269	2	555	767	0	2
270	2	555	767	0	2
192	1	763	763	176	3
527	1	1,011	762	519	3
349	2	414	753	0	2
415	1	745	748	412	3
361	1	733	733	371	3
350	2	714	720	0	2
329	1	685	685	327	3
356	1	660	660	328	3
307	2	867	635	0	2
531	1	170	622	544	3
509	1	154	605	505	3
569	1	427	594	567	3
75	1	585	585	69	3
398	2	505	584	0	2
28	1	698	581	25	5
232	2	462	572	0	2
440	2	261	554	0	2
319	2	292	546	0	2
457	2	219	532	0	2
52	1	476	522	46	3
220	2	331	516	0	2
451	2	727	510	0	2
20	1	1,615	497	27	4
597	2	219	497	0	2
81	1	493	492	93	3
30	1	607	490	33	5
57	1	468	486	66	3
272	2	530	477	0	2
188	2	479	475	0	2
386	2	140	471	0	2
312	2	439	466	0	2
211	1	444	444	245	3

NodeNum	NodeType	Trips_ALL	Trips	PrevNode	Tier
154	1	297	441	150	3
267	1	422	441	265	3
294	1	485	434	247	3
71	1	432	431	68	3
51	1	474	425	56	4
293	1	441	424	268	3
303	2	149	416	0	2
561	2	461	416	0	2
173	1	415	415	179	3
484	2	322	399	0	2
193	2	124	399	0	2
421	1	396	396	420	3
439	1	384	386	434	3
470	1	530	385	441	3
401	1	320	378	357	3
94	2	0	376	0	2
80	1	339	365	78	4
355	1	360	360	358	3
461	1	359	359	460	3
502	1	353	353	518	4
157	2	1,437	352	0	2
388	1	351	351	413	3
306	1	320	339	301	3
369	1	330	330	334	3
575	1	366	319	573	3
139	2	311	311	0	2
497	1	304	304	473	4
175	2	193	303	0	2
229	1	297	297	273	6
435	1	194	295	428	3
524	1	387	278	511	3
373	1	317	277	375	3
599	1	210	277	600	3
132	1	403	273	121	4
492	1	273	273	485	3
532	2	651	273	0	2
295	1	303	272	314	4
402	1	270	270	380	4
520	2	244	269	0	2
297	1	350	267	315	3
344	1	332	266	332	3
48	1	194	264	45	5
454	2	207	263	0	2
305	2	131	251	0	2
318	1	229	230	310	3
317	1	229	229	292	3
549	1	217	217	536	4
550	1	217	217	546	4
126	1	215	215	136	3
382	1	212	212	390	3
530	2	154	210	0	2
105	1	203	203	102	3
541	2	367	203	0	2
359	1	201	201	394	3
49	1	194	194	45	5
128	1	189	189	152	5
196	1	180	180	204	6
90	1	178	178	83	5
474	1	164	178	504	3
85	2	1,060	176	0	2
93	2	669	176	0	2
Contd…					

REFERENCES

Andrey, J. (Editor). 1995. Transport Planning and Policy Issues: Geographical Perspectives, Department of Geography Publication Series Number 45, University of Waterloo, Ontario, Canada.

Asian Development Bank. 1997. Guidelines for the Economic Analysis of Projects. Economics and Development Resource Center.

Atkinson, D. M., Deadman, P., Dudycha, D. and Traynor, S. 2005. Multi-criteria Evaluation and Least Cost Path Analysis for an Artic All-weather Road. *Applied Geography* 25: 287-307.

Bachand, D. M. and Berhand, P. K. 1998. Textbook Crossing for Canada. *Directional Drilling* 3 (2): 45.

Barwell, I. 1996. Transport and the Village. Findings from African Village-Level Travel and Transport Surveys and Related Studies. World Bank Discussion Paper No. 344, Africa Region Series, The World Bank, Washington D. C.

Barwell, I. J., Edmonds, G. A., Howe, J. D. G. F. and de Veen, J. 1985. Rural Transport in Developing Countries, Intermediate Technology Publications, London, United Kingdom.

Beaumont, J. R. 1987. Location Allocation Models and Central Place Theory. In Ghosh, A. and Rushton, G. (Editors). Spatial Analysis and Location Allocation Models, New York, Van Nostrand Reinhold Company.

Beenhakker, H. 1987. Rural Transport Services. Intermediate Technology Publications. United Kingdom.

Bennett, D. 2000. The History and Aesthetic Development of Bridges. In Ryall, M. J., Parke, G. A. R. and Harding, J. E. (Editors). The Manual of Bridge Engineering. First Edition. London: Thomas Telford.

Blaikie, M. P., Cameron, J. and Seedon, J. D. 1979. The Struggle for Basic Needs in Nepal. Development Center of the Organization for Economic Cooperation and Development, Paris.

Bridges to Prosperity, http://www.bridgestoprosperity.org/ accessed 15 December 2006.

Brundtland Commission. 1987. Our Common Future: World Commission on Environment and Development. Oxford University Press.

Bryceson, D. F., Maunder, D. A. C., Mbara, T. C., Kibombo, R. and Davis, A. S. C., and Howe, J. D. G. F. 2003. Sustainable Livelihoods, Mobility and Access Needs, Department for International Development and TRL Limited

Cartwright, T. J. 1987. Information Systems for Planning in Developing Countries: Some Lessons from the Experience of the United Nations Centre for Human Settlements, Habitat International 11 (1): 191-205.

Central Bureau of Statistics. 2004. Statistical Pocket Book, National Planning Commission Secretariat, Kathmandu, Nepal.

Central Bureau of Statistics. 2005. Statistical Pocket Book, National Planning Commission Secretariat, Kathmandu, Nepal.

Chambers, R. 1983. Rural Development: Putting the Last First. Longman. London, Lagos and New York.

Clark, T. 2002. The Policy Process: A Practical Guide for Natural Resource Professionals, Yale University Press, New Haven and London.

Clarke, G. 1997. Applied Spatial Modeling for Business and Service Planning. *Computer, Environment and Urban Systems* 21 (6): 373-376.

Chamber, R. 1980. Rural Poverty Unperceived – Problems and Remedies. Washington DC: World Bank Staff Working Paper 654.

Chhatkuli, R. and Kayastha, D. 2005. Towards a National Geographic Information Infrastructure: Overcoming Impediments to the Development of Spatial Data Infrastructure in Nepal.

Christaller, W. 1966. Central Places in Southern Germany. Prentice-Hall, New Jersey.

Dale, A. 2001. At the Edge: Sustainable Development in the 21st Century, UBC Press, the University of British Columbia, Vancouver, Canada.

Dennison, P. H. 1988. The Unique Qualities of a Geographic Information System: *A Commentary. Photogrammetric Engineering and Remote Sensing* 54 (11): 1547-1549.

Department for International Development. 2003. Implementing the Rural Access Program in Nepal. Position Paper: Use of Geographic Information Systems in RAP Districts, Nepal.

Department of Transportation, New Brunswick, Canada, http://www.gnb.ca/0113/footbridges/footbridges-e.asp accessed 22 December 2006.

Department of Roads, Ministry of Physical Planning and Works, Nepal. http://www.dor.gov.np/ accessed 20 December 2006.

Devkota, B. and Rajbhandari, G. 2004. Local Heroes: Simple Bridge Technology in Nepal. *A definitive publication for bridge professionals worldwide, Bridge Design & Engineering,* 35: 39-40, Second Quarter.

Dixon-Fyle, K. 1998. Accessibility Planning and Local Development: The Application Possibilities of the Integrated Rural Accessibility Planning Methodology, International Labor Organization.

Dudycha, D. 2006. Example of Spatial Interaction Modeling Using ArcGIS, Department of Geography, University of Waterloo, Waterloo, Ontario, Canada.

Edmonds, G. and Barwell, I. 1993. Accessibility and Siting of Facilities and Services, The World Bank, Washington D. C.

Environmental Systems Research Institute. 2005. ArcGIS 9, ArcGIS Network Analyst Tutorial, Environmental Systems Research Institute, Redlands, CA, USA.

Environmental Systems Research Institute. 2006. Spatial Interaction Modeling. ARC/INFO On-line Help Documentation. Redlands, CA, USA.

Farrington, J. and Farrington, C. 2005. Rural Accessibility, Social Inclusion and Social Justice: Towards conceptualization. *Journal of Transport Geography* (13):1-12.

Fellmann, J. D., Getis, A. and Getis, Judith. 2003. Human Geography: Landscapes of Human Activities. Seventh Edition. McGraw Hill Companies.

Filani, M. O. 1993. Transport and Rural Development in Nigeria. *Journal of Transport Geography* 1 (4): 248-254.

Foresman, T. W. (Editors). 1998. The History of Geographic Information Systems: Perspectives from the Pioneers, Prentice Hall Inc.

Freer, R. 1991. Bio-engineering: The Use of Vegetation in Civil Engineering. *Construction and Building Materials* 5 (1): 23-26

Gannon, C., Gwilliam K., Liu, Z. and Malmberg C. C. 2001. Transport: Infrastructure and Services.

Geertman, S. C. M. 1995. GIS and Models of Accessibility Potential: An Application in Planning. *International Journal of Geographical Information Systems* 9: 67-80.

Ghosh, A. and Rushton, G. (Editors). 1987. Spatial Analysis and Location Allocation Models, New York, Van Nostrand Reinhold Company.

Golledge, R. G. and Timmermans H. (Editors). 1988. Behavioural Modelling in Geography and Planning, Croom Helm Ltd., London, New York and Sydney.

Griesbaum, M. 2003. Rural Centers and Integrated Transport Network in Nepal. Ph. D. Thesis, Tribhuvan University, Central Department of Geography, Kathmandu, Nepal.

Gray, D., Shaw, J. and Farrington, J. 2006. Community Transport, Social Capital and Social Exclusion in Rural Areas, *Area* 38(1): 89-98.

Halden, D., Jones, P. and Wixey, S. 2005. Measuring Accessibility as Experience by Different Socially Disadvantaged Groups: Working Paper No. 3, Accessibility Analysis Literature Review, Transport Studies Group, University of Westminister

Hall, G. and Bowerman, R. 2000. Using GIS to Evaluate the Accessibility of Family Planning Services in the Central Valley of Costa Rica.

Hall, G. B., Feick, R. D. and Bowerman, R. L. (nd). Problems and Prospects for GIS-based Decision Support Applications in Developing Countries, Faculty of Environmental Studies, University of Waterloo, Waterloo, Ontario, Canada.

Handy, S. L. and Niemeier, D. A. 1997. Measuring Accessibility: An Exploration of Issues and Alternatives. *Environment and Planning A* 29:1175-1194.

Hansen, W. G. 1959. How Accessibility Shapes Land Use. *Journal of American Planning Institute* (25) 73-76.

Harvey, M. and Hi-Hwawu. 2000. GIS Software for Measuring Space-Time Accessibility in Transportation Planning and Analysis. *GeoInformatica* 4:2, 141-159.

Haynes, R., Lovett, A., Sunnengerg, G. 2003. Potential Accessibility, Travel Time and Consumer Choice: Geographical Variations in General Medical Practice Registrations in Eastern England. *Environment and Planning A* 35: 1733-1750.

Helvetas Nepal. Trail Bridge Sub-Sector Project. 2005. Central Bridge Register and Planning and Monitoring System, Kathmandu, Nepal.

Helvetas Nepal. Trail Bridge Sub-Sector Project. 2005. Local Bridge Register and Planning and Monitoring System, Kathmandu, Nepal.

Heywood, I. 1990 Geographic Information Systems in Social Sciences. *Environment and Planning A* 22: 849-854.

His Majesty's Government, Ministry of Local Development, Department of Local Infrastructure Development and Agricultural Roads. 2005. Second Edition. Integrated Rural Accessibility Planning. Kathmandu, Nepal.

His Majesty's Government, Ministry of Local Development, Department of Local Infrastructure Development and Agricultural Roads. 1999. Kathmandu, Nepal.

His Majesty's Government, Ministry of Local Development. 1999. Approach for the Development of Agricultural and Rural Roads. Kathmandu, Nepal.

Hodgart, R. L. 1978. Optimizing Access to Public Services: A Review of Problems, Models and Methods of Locating Central Facilities. *Progress in Human Geography* 2: 17- 48.

Horner, M. 2004. Exploring metropolitan Accessibility and Urban Structure. *Urban Geography* 25 (3): 264-284.

Howe, J. and Richards, P. 1984. Rural Roads and Poverty Alleviation, Intermediate Technology Publications, London, United Kingdom.

Howe, J. 1997. Transport for the Poor or Poor Transport? A General Review of Rural Transport Policy in Developing Countries with Emphasis on Low-income Areas. Geneva: International Labor organization.

Hoyle, B. and Knowles, R. (Editors). 1998. Modern Transport Geography, Second Edition, John Wiley & Sons Ltd, England.

Ilhamdaniah, T. M. and Sherif, A. (nd). Evaluating the Planning of Social Infrastructures in Ahmedabad, India.

Ingram, D. R. 1971. The concept of Accessibility: A Search for an Operational Form. *Regional Studies* 5 101-107.

International Centre for Integrated Mountain Development and Mountain Environment and Natural Resources Information System. 1996. Geographic Information Systems and their Applications - Training Manual for Policy-Makers, Kathmandu, Nepal.

International Centre for Integrated Mountain Development and Mountain Environment and Natural Resources Information System. 1996. Application of Geographic Information Systems and Remote Sensing, Training Manual for Managers (Vols. I & II), Kathmandu, Nepal.

International Centre for Integrated Mountain Development and Nepal Central Bureau of Statistics. 2004. Mapping Nepal Census Indicators 2001 and Trends. Kathmandu, Nepal.

Jones, S. R. 1981. Accessibility Measures: A Literature Review, Transport and Road Research Laboratory, Transport Operations Department, Crowthorne, Berkshire, United Kingdom.

Jones, V. and Howells, J. 2000. Suspension Bridges. In Ryall, M. J., Parke, G. A. R. and Harding, J. E. (Editors) The Manual of Bridge Engineering. First Edition. London: Thomas Telford.

Kanbur R. and Venables A. J. (Editors). 2005. Spatial Inequality and Development, Oxford University Press.

Kessides, C. 1993. The Contributions of Infrastructure to Economic Development: A Review of Experience and Policy Implications, World Bank Discussion Papers No. 213.

Kliskey, A. D. 1995. The Role of Functionality of GIS as a Planning Tool in Natural Resource Management. *Computer, Environment and Urban Systems* 19 (1): 15-22.

Klosterman, R. 1995. The Appropriateness of Geographic Information Systems for Regional Planning in the Developing World. *Computer, Environment and Urban Systems* 19 (1): 1-13.

Kotze, D. 1997. Development Administration and Management, A Holistic Approach. J. L. Van Schaik Publishers.

Kwan, M., Murray, A. T., O'Kelly, M. E., and Tiefelsdorf, M. 2003. Recent Advances in Accessibility Research: Representation, Methodology and Applications. *Geographical Systems* 5: 129-138.

Lake, R. W. 1993. Planning and Applied Geography: Positivism, Ethics and Geographic Information Systems. *Progress in Human Geography* 17 (3): 404-413.

Lake, R. W. 1992. Planning and Applied Geography. *Progress in Human Geography* 16 (3): 414-421.

Lebo, J. and Schelling, D. 2001. World Bank Technical Paper No. 496. Design and Appraisal of Rural Transport Infrastructure: Ensuring Basic Access for Rural Communities. The World Bank. Washington, D.C.

Liu, S. and Zhu X. 2004. An Integrated GIS Approach to Accessibility Analysis. *Transactions in GIS* 8 (1): 45-62

Longley, P., Goodchild, M., Maguire, D., and Rhind, D. 2005. Geographic Information Systems and Science. Second Edition, John Wiley & Sons, Ltd, ESRI Press.

Losch, A. 1954. The Economics of Location. Yale University Press, Connecticut.

Luo, W. and Wang, F. 2003. Measures of Spatial Accessibility to Health Care in a GIS environment: Synthesis and a Case Study in the Chicago Region. *Environment and Planning B: Planning and Design* 30: 865-884.

Maguire, D. J. 1991. An Overview and Definition of GIS. Geographic Information System, 1st edition, John Wiley and Sons.

Mapping, Analysis & Design. 2005. Creating Spatial Data: Table Digitizing with ArcMap, Faculty of Environmental Studies, University of Waterloo, Waterloo, Ontario, Canada.

Mapping, Analysis & Design. 2005. Creating Spatial Data: Heads-up Digitizing with ArcMap, Faculty of Environmental Studies, University of Waterloo, Waterloo, Ontario, Canada.

Maos, J. O. 1983. Efficiency of Services in Dispersed and Concentrated Land Settlement: A Comparison. *Geografiska Annaler. Series B, Human Geography* 65 (1): 47-55.

Martin, D. 1991. Geographic Information Systems and their Socioeconomic Applications. London and New York.

Messerli, B., Hofer, T. and Wymann, S. (Editors). 1993. Himalayan Environment: Pressure - Problems - Processes. Institute of Geography, University of Berne, Switzerland.

Ministry of Local Development, Trail Bridge Section. 2005. Transport Infrastructure Map, Scope of Map Production, Utilization and Updating. Kathmandu, Nepal.

Ministry of Local Development, Department of Local Infrastructure Development and Agricultural Roads. 2004. Environmental and Social Management Framework: Rural Access Improvement Project, Kathmandu, Nepal.

Miller, H. J. and Wu, Y. H. 2000. GIS Software for Measuring Space-time Accessibility in Transportation Planning and Analysis. *Geoinformatica* 4 (2): 141-159.

Mitchell, B. 2002. Resource and Environmental Management, Second Edition, Harlow, England.

Mooneyhan, D. W. 1998. International Applications of GIS. In Foresman, T. W. (Editor). The History of Geographic Information Systems: Perspectives from the Pioneers, Prentice Hall Inc.

Morris J. M. 1979. Accessibility Indicators in Transport Planning. *Transportation Research Part A, General* 13A: 91-109.

Mosely, M. J. 1979. Accessibility: The Rural Challenge. Menthum, London.

Mountain Environment and Natural Resources Information System. 1994. Case Study Series No. 2, Application of GIS to Rural Development Planning in Nepal, Spatial Analysis of a Rural Service Delivery System. Kathmandu, Nepal.

Naude, A., de Jong, T. and van Teeffelen, P. 1999. Measuring Accessibility with GIS-Tools: A Case Study of the Wild Coast of South Africa. *Transactions in GIS* 3 (4): 381-395.

Nepal Central Bureau of Statistics and International Centre for Integrated Mountain Development. 2004. Districts of Nepal: Indicators of Development 2001. Kathmandu, Nepal.

Nepal Trail Bridge Section. http://www.nepaltrailbridges.org accessed 19 December 2006.

Nepal Trail Bridge Section. 2004. Transport Infrastructure Map, Ministry of Local Development Kathmandu, Nepal.

Nicholls, S. 2001. Measuring the Accessibility and Equity of Public Parks: A Case Study using GIS. *Managing Leisure* 6: 201-219.

Nutley, S. 1998. Rural Areas: The Accessibility Problem. In Hoyle, B. and Knowles, R. (Editors). Modern Transport Geography. Second Edition, John Wiley & Sons Ltd, England.

Odoki, J. B., Kerali, H. R. and Santorini, F. 2001. An Integrated Model for Quantifying Accessibility Benefits in Developing Countries. *Transport Research Part A* 35: 601-623.

Oppenheim, N. 1980. Applied Models in Urban and Regional Analysis, Polytechnic Institute of New York.

Okhaldhunga District Transport Master Plan. 2002. District Development Committee, Okhaldhunga, Nepal.

Parr, J. B. 1978. Models of Central Place System: A More General Approach. *Urban Studies* 15: 35-49.

Patel, N. R. 1979. Locating Rural Social Service Centre in India. *Management Sciences* 25: 22-30.

Patton, T. A. 1976. The Effect of Accessibility on Residential Density, Special Report 7, Department of Civil Engineering, University of Melbourne, Melbourne.

Porter, G. 2002. Living in a Walking World: Rural Mobility and Social Equity Issues in Sub-Saharan Africa. *World Development* 30 (2): 285-300.

Poudel, R. K., Humagain, I. R., Joshi, N. L., Bhattarai, M., Dallakoti, K. N., Khanal, B. N, Koirala, B., Khadka, P. B., Shrestha, J. K., Jaishi, K., Rajbhandari, G., Nepal, T. R. and Devkota, B. 2003. A Course Manual on Pedestrian Trail Bridges for Bachelor of Civil Engineering, Tribhuvan University, Institute of Engineering, Kathmandu, Nepal.

Ravallion, M. 2000. On the Urbanization of the Poverty, World Bank (as cited in Malkin, 2003).

Rich, D. C. 1980. Concepts and Techniques in Modern Geography No. 26: Potential Models in Human Geography, Macquarie University, Australia.

Rowbotham, D. N. and Dudycha D. 1998. GIS Modelling of Slope Stability in Phewa Tal Watershed, Nepal. *Geomorphology* 26: 151-170.

Rushton, G. 1984. Use of Location Allocation Models for Improving the Geographical Accessibility of Rural Services in Developing Countries. *International Regional Science Review* 9: 217-240.

Rushton, G. 1988. The Roepke Lecture in Economic Geographic: Location Theory, Location Allocation Models, and Service Development Planning in the Third World. *Economic Geography* 64: 97-120.

Ryall, M. J., Parke, G. A. R. and Harding, J. E. (Editors). 2000. The Manual of Bridge Engineering. First Edition. London: Thomas Telford.

Ryan, K. (Editor). 1993. Trails for the Twenty First Century: Planning, Design, and Management Manual for Multi-Use Trails, Rails to Trails Conservancy, Island Press, Washington D. C.

Sarkar, A. Integrated Rural Accessibility Planning. 2005: Application in Rajasthan, India and Bangkok, Thailand, International Labor Office.

Sarkar, A. and Ghosh, D. 2000. Identification and Prioritization of Access Problems in Rural Areas. *Development Southern Africa* 17 (1): 149-156.

Scott, A. J. 1969. Dynamic Location Allocation Systems: Some Basic Planning Strategies, Department of Geography, University of Toronto, Discussion Paper No. 3.

Sheppard, E. S. 1973. A conceptual Framework for Dynamic Location Allocation Analysis, Department of Geography, University of Toronto, Discussion Paper No. 14.

Shrestha, B. Bajracharya, B., Pradhan, S. and Rajbhandari, L. 2003. GIS for Municipal Planning: A Case Study from Kirtipur Municipality, International Centre for Integrated Mountain Development, Kalthmandu, Nepal.

Steg, L. and Gifford, R. 2005. Sustainable Transportation and Quality of Life. *Journal of Transport Geography* (13): 59 - 69.

Storbeck, J. E. 1988. The Spatial Structuring of Central Places. *Geographical Analysis* 20 (2): 93-110.

Suspension Bridge Program, Bhutan, http://www.helvetas.org.bt/sbp.htm accessed 15 December 2006.

Swiss Agency for Development and Cooperation, Kathmandu, Nepal. http://www.sdc.org.np/ accessed 20 December 2006.

Talen, E. 1997. The Social Equity of Urban Services Distribution: An Exploration of Parks Access in Pueblo, Colorado and Macon, Georgia, *Urban Geography* 18 (6): 521-541.

Taylor, P. J. 1983. Quantitative Methods in Geography: An introduction to Spatial Analysis, Waveland Press, Inc.

Tewari, V. K. 1992. Improving Access to Services and Facilities in Developing Countries. *International Regional Science Review* 15: 25-37.

Trail Bridge Section. 2005. Nepal Trail Bridge Record, Kathmandu, Nepal.

United Nations. 2005. Department of Economic and Social Affairs, Population Division, World Population.

United States Geological Survey (USGS), http://wwwrcamnl.wr.usgs.gov/sws/cableways/descr.htm accessed 25 December 2006.

Vasconsellos, E. 1997. Rural Transport and Access to Education in Developing Countries: Policy Issues. *Journal of Transport Geography* 5 (2): 127-136.

Vickerman, R. W. 1974. Accessibility, Attraction and Potential: A Review of Some Concepts and their Use in Determining Mobility. *Environment and Planning A* (6): 675-691.

Victor, J. 1980. Essentials of Bridge Engineering, New Delhi: Oxford & IHB Publishing Company.

Webb E. L. and Thiha. 2002. Integrating Social Preference in GIS-Aided Planning for Forestry and Conservation Activities: A Case Study from Rural South East Asia. *Environmental Management* 30 (2): 183-198.

Wachs, M. and Kumagai, T. G. 1972. Physical Accessibility as a Social Indicator, School of Architecture and Urban Planning, California University at Los Angeles, California.

Wang, F. 2006. Quantitative Methods and Applications in GIS, Taylor & Francis Group, Boca Raton, London, New York.

Wanmali, S. 1970. Regional Planning for Social Facilities, An Examination of Central Place Concepts and Their Application: A Case Study of Eastern Maharastha, National Institute of Community Development, Hyderabad-30, India.

Weber, J. 2006. Reflections on Future of Accessibility. *Journal of Transport Geography* 14: 399-400.

Wilson, A. 1967. A Statistical Theory of Spatial Distribution Models. *Transportation Research* 1: 253-269.

Wilson, A. 1974. Urban and Regional Models in Geography and Planning, Chichester, UK: John Wiley and Sons.

Wilson, A. G. 1971. A Family of Spatial Interaction Models and Associate Development. *Environment and Planning A* 31-32.

Xiang, W. N. 1996. A GIS Based Method for Trail Alignment Planning. *Landscape and Urban Planning* 35: 11-23.

Yang, D. H., George, R. and Mullner, R. 2006. Comparing GIS-Based Methods of Measuring Spatial Accessibility to Health Services. *Journal of Medical Systems* 30 (1): 23-32.

Yeh, A. G. 1991. The Development and Applications of Geographic Information Systems for Urban and Regional Planning in the Developing Countries. *International Journal of Geographical Information Systems* 5 (1): 5-27.

Yeh, A. G. and Batty, M. 1990. Applications of Geographic Information Systems in Urban and Regional Planning. *Environment and Planning B, Planning & Design* 17: 369-374.