GIS based rural road network planning for developing countries

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ABSTRACT: Rural transport and accessibility problems cause isolation, which is one of interlocking dimensions of poverty. Improving rural access to facilities, services and employment opportunities are now emphasized as an effective means towards poverty alleviation. Travel and transport are the means by which people gain access to the facilities and services they need for the everyday life. Distance, time, effort and cost are the measures of the level of access to facilities and if they are too high they constrain opportunities and potential for development. The rural settlements devoid of all weather road connectivity have poor accessibility and thus the immobility of their population. The aims of intervention to improve rural transport should therefore be to upgrade access to facilities to an acceptable level. A well planned road system in rural areas is one of the most important infrastructure elements which improves rural accessibility and contributes to the rural development as a whole. The rural road network planning methodology presented in this research paper is based on accessibility concept and implemented using GIS technology. A new index of accessibility is designed which evaluates various rural road link options for their efficiency in accessing the missing functions in the unconnected settlement. The accessibility based approach of rural road planning offers maximum benefit to the unconnected settlement in terms of access to various facilities or the main road network in a coordinated fashion by maintaining an integrated road system. A GIS based technique for the analysis of alignment of new road link options has been developed which considers the topographic and land use characteristics of the area. GIS-T software package, TransCAD, is used to organise the database for road alignment and implementation of the developed rural road planning methodology.

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CE Database subject headings: Rural road; Planning; access; accessibility; GIS; Database; Road network.

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INTRODUCTION

Despite development gains in some areas, the world is still home to 1.1 billion extremely poor people. Rural areas of developing countries contain over three-quarters of the world's poor. A key element of poverty is isolation expressed as the lack of access people have to basic, social and economic goods, facilities and opportunities. The rural settlements devoid of all weather road connectivity have poor accessibility and thus the immobility of their population. The rural poverty and immobility go hand in hand. Unless the distance that separates the rural population from important functions/ facilities are bridged, the effort to raise their living standards can not succeed. The proper planning and development of rural road network therefore, assumes its importance in terms of providing connectivity and utilisation of resources.

The developing countries have a huge network of rural roads, which mainly consists of unsurfaced-paths and tracks, as the major share of their population resides in rural areas. A large number of rural settlements in these countries are yet to be connected by all weather roads. In India alone, there are 580,781 inhabited rural settlements (Statistical Abstract of India 1997) out of which 95,935 rural settlements are yet to be connected by all weather roads (MORD 2007). All weather rural roads are one of the most important rural transport infrastructure elements which are seen as the conduit that could facilitate rural development. Access in rural areas is poor as the existing roads are frequently impassable, especially during the rainy season, limiting transport services and restraining access and, therefore, constraining development.

The connotation of rural roads for a developing country, like India, is different from the developed countries. Rural roads in developed countries are primarily the roads passing through rural and agricultural areas whereas in the context of a developing country, it is a low

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volume road which mainly provides connectivity to rural settlement. Rural roads, as defined in the Third Twenty Year Road Development Plan (1981-2000) of India, are the tertiary road system, comprising Other District Roads (ODR) and Village Roads, which serve as the feeder road to the primary (National and State Highways) and secondary (Major District Roads) road systems and link rural settlements with the nearest market centers, or to any other settlement (M.O.S.T. 1984). There are other lower level roads in rural areas, such as paths and tracks, which serve important functions but are not covered under the above definition and classification of rural roads. However, from network planning point of view rural road is an all weather road that connects a rural settlement with any other settlement, to the market, or to the primary and secondary road system in the area.

Various models for planning rural road network had been developed by different research organisations, educational institutions and consultants but in actual practice they have not been of much help to implementing agencies. Issues such as comprehensive database of the area, aspiration of local people and their access needs, land acquisition issues, alignment and construction cost of road links, upgradation of existing fair weather roads to all weather standard etc, are not properly addressed in these models. The overall practical utility of these models is, therefore, limited. To overcome these limitations rural road planning methodology should be based on comprehensive database of the area and should efficiently caters to the rural travel requirement. The rural road network planning methodology, presented in this research paper, is developed in a GIS framework and is based on accessibility concept. The accessibility based approach of road planning offers maximum benefit to the unconnected settlement in terms of access to various facilities or the main road network in a coordinated fashion by maintaining an integrated road system.

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ACCESS NEEDS OF RURAL COMMUNITIES

Travel and transport are related to needs of access to facilities or services and movement of goods. The access needs and travel patterns of population residing in rural area can be broadly categorized as: subsistence, economic development, improvement of human resources and other social and business purposes. It varies from region to region depending on topography, type of agricultural and other economic activities and practices and local culture and traditions. However, it is possible to identify some trends in access needs of rural population in developing countries.

The basic daily subsistence needs of rural population are water, food and fuel for cooking. Access to these basic commodities and their transport in adequate quantities for subsistence is the overriding priority for rural household. Good access to uncontaminated water is important as it is basic necessity for good health and hygiene of household and several trips are needed per household per day, particularly in arid zones. Access to fire wood is not very critical but on an average 0.7 to 1 trip per day is needed to meet this requirement. Poor access to water and fire wood, involving excessive time in transport, may well constrain potential to produce surplus crops to move into market economy. Distance to household plots is not usually great and it can be reduced through land consolidations but transport of produce at harvest can be constraint due to the large transport need in a short period of time. Access to grinding mill is needed to eliminate the considerable effort involved in grinding by hand.

Access to education is very important for the future development of families, human capital and national development. The improved access to health services safeguards the welfare and productive capacity of the households and relieves one of the major anxieties of isolated rural living.

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Economic development increases the demand for improved access to a range of other facilities. Good access to markets, particularly external, is needed to get good prices for produce with the least cost penalty for transport. As the households in rural area progress from mainly subsistence living to marketing of crops a greater need for access to resources, such as fertilizers, tools and equipment and other agricultural and household inputs arises. This in turns increases the demand for access to business, financial and government facilities. As the rural community develops an increasing demand for access for social reasons such as leisure, sport, shopping, which will be mainly external to the village, is generated.

CHARACTERISTICS OF RURAL TRANSPORT

Transport for rural communities in its totality encompasses the movement of rural people and their goods to meet their domestic, economic and social needs, by any means, along tracks, paths and roads. Research works carried by World Bank and International Labor Organization (ILO) shows that transport in rural areas is carried out mostly on foot or with the aid of intermediate means of transport (Edmonds et al. 1994). Studies of transport patterns shows that rural transport comprises mainly short trips (less than 10 km) in and around the village carrying relatively small loads, often on earthen paths and tracks (Dawson et al. 1993). The transport system in rural areas of developing countries can be characterized by their transport infrastructure, modes of transportation and transport services which are discussed in detail in subsequent sections.

Rural transport infrastructure

The rural transport infrastructure consists of roads, tracks, paths and their associated bridges and other forms of water crossings. One of the major constraints on access to rural areas is

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the poor condition of this infrastructure. For the majority of villages in developing countries the principle means of access is along roads-usually unsurfaced-paths and tracks. Before the start of Prime Minister's rural road program (PMGSY) in India, 40% villages in the range of 1000-1500 population range did not have direct access to any standard road and 58% did not have access to an all weather road. More than 78% of villages in India are below 1000 population and, therefore, road access can be assumed to be worse than this for other villages with smaller population. There are many countries that are poorer and thus may be presumed to have severe rural access problems than India. Most tropical and subtropical countries in the world are characterized by wet weather extending over several months during which earth roads become impassable, and footpath becomes slippery and dangerous. Unfortunately these are also seasons of the year when agricultural activity is at its highest and farmers need access to their fields, supplies of inputs and markets.

Modes of transport

The predominant mode of transport in rural areas, particularly for "internal" trips, is walking carrying loads on head or shoulders. Vehicles tend to be used by the villagers if they can be seen to pay for themselves and are generally only introduced when the movement of produce for marketing becomes unmanageable by human beings. A combination of low incomes and limited infrastructure make the conventional motorized vehicles largely unaffordable and unsuitable. The means of transport for rural households, therefore, lie in the lower cost range of what are termed "intermediate' means of transport (IMT)" i.e. intermediate between human porterage and conventional motorized vehicles. Some of the popular types of IMT in rural areas are wheelbarrow, handcart, cycle with carrier, cycle trailer, ox-cart, pack donkey, motorcycle, motorcycle trailer, single axle Tractor Trailer etc (Denis 1995). The main advantage of IMT is in reducing the time and effort involved in rural travel and transport as

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compared with human porterage. Wheelbarrows, carts and trailers improve access by greatly reducing the number of trips needed to transport agricultural crops or other materials thus releasing substantial block of time which can be used in other activities. The bicycles improve the access through greater speeds which reduce travel times and make longer trips feasible. This mode is particularly important in providing access to work opportunities, health facilities and more distant markets. The main role of IMT in rural area is to improve access by moving agricultural inputs and produce in and around the village, grain to the mill and produce to the markets and collection points that are within a reasonable distance.

Although affordability and, therefore, initial cost is usually a ruling criterion in the selection of an IMT, operating costs is also one of the deciding factor because of their effect of net income received from marketing of produce and on the ability of the owner to afford repairs and to keep the IMT operational (Denis 1995). Other selection criterions in rural areas for choosing an IMT are appropriateness for physical conditions, topography and infrastructure.

Transport services

Transport services involve the movement of passengers or goods for a fee by an operator working as a business or employee of a business. They normally operate on popular routes where traffic levels are high enough for the services to be economical, for instance linking settlements to markets or a rural center. Transport services are particularly important for providing access to external facilities. Access to external markets is essential for agricultural development. The major demand, and hence the best price, for agricultural produce, is in the main population centers where people tend to buy rather than grow their food. Lack of effective transport services significantly constraints the opportunities that households can gain from access to these facilities, imposing severe penalties through lengthy travel times

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substantially reducing the volume of produce that can be transported and sometimes forcing farmers to sell at low prices to traders at the farm gate. In most of the developing nations effective transport services are often provided by a range of smaller vehicles, based on motorcycles or small diesel engines, which are better matched to the needs of the rural communities and provide services right into the villages (Ellis 1995). Good road infrastructure reduces vehicle operating and maintenance cost encouraging better transport services in rural areas. Connectivity of settlements through all weather roads facilitate growth of transport services in rural areas which helps in improving overall accessibility of settlements.

EXISTING TECHNIQUES OF RURAL ROAD PLANNING

There are many approaches to rural road planning. Prioritising settlements based on their population and socioeconomic characteristics and connecting them with shortest road link are the simplest approach to rural road planning. Methods based on minimal spanning tree concept, inter settlement interaction approach, accessibility criteria etc are more rational and scientific approaches to rural road planning. In India, the rural road planning at national level were guided by the long term Twenty Year Road Development Plans, which provided guidelines to prioritise settlement connectivity on the basis of their population and to achieve certain road density as a result of road development in the region (Road Development Plan of India 1981-2001 1984). There were many shortcomings in adopting these guidelines as the basis for rural road planning. The road mileage targets fixed in the plan were based on certain empirical formulae. Instead of formulating the road development plans at local or regional level, pre-calculated road mileage were assigned by the plan and states and districts were required to reconcile their needs with the over all target thus assigned, without considering

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for the actual accessibility needs of a region (Mahendru et al. 1983). The master plans prepared for rural road development, based on these guidelines, result in direct connectivity of settlements of qualifying population range with the nearest connected settlement or to the nearby existing roads. Network thus developed was suboptimal and not efficient to cater the functional requirements of settlement. Also, there are no guidelines to decide inter settlement connectivity. This approach of rural road planning thus led to the development of inefficient network and poor utilization of scarcely available resources.

Swaminathan et al. (1982) used the concept of minimum spanning tree for connecting the settlements to existing nearby roads or to the nearest market. In this method, it was claimed that the network generated is optimal but no analysis for optimality was carried out. Kumar and Tilloston (1985) proposed the rural road network planning methodology based on minimization of total cost, which consisted construction and travel costs. Alternative networks were generated from a set of predetermined road links by providing connectivity to the rural settlements with different link options. The optimum network was selected as the one with minimum construction cost, which was generated using minimum spanning tree concept. Here, it was assumed that all the access needs of a settlement gets satisfied if it is connected to a market, which is not true. The set of link options, from which the alternative networks were generated, were only a predetermined few. The method suggested does not consider an integrated area development approach and, therefore, it’s over all functional utility is questionable.

UNCHS (1985) suggested procedures for generation of network option for connectivity, and then, based on a set of simple evaluation criteria or indicators screening the options to a few which are considered for detailed engineering/economic evaluation. It also proposes to evaluate the road network by developing indicators based on graph-theoretic measure of connectivity in a network and/or gravity concept based measure of spatial accessibility. The

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draw back of these measures is that they are limited to the analysis of topological properties of the network and do not deal with characteristics such as capacity, type of use and cost of construction. The procedure is aimed to identify the most accessible routes between settlements.

Mahendru et al. (1983, 1985, 1988, 1989) used the concept of settlement interaction, link efficiency, route efficiency and network efficiency to generate, analyse and evaluate alternative rural road linkage pattern. Integrated area development approach was considered to develop the road network so that it serves the area in a balanced way. Gravity hypothesis was used to quantify the inter-settlement interaction, based on level of socio-economic development, population and spatial separation between settlements. Centrality score was used as the composite index to quantify the level of socio-economic development and the interaction between two settlements was considered proportional to the difference in their centrality scores. Alternative networks were generated using various criteria like maximum link efficiency, minimum total link length, and minimum total operating cost and fully developed network. These were then tested for their total cost, which consisted of construction and operating costs, to arrive at the optimal network. In spite of its rational and scientific treatment to various aspects of rural road planning, there are some deficiencies too in this approach. The Gravity hypothesis, used to model the hidden pattern of inter-settlement interaction, gives erroneous results when the centrality scores of interacting settlements are same (in that case the interaction computed through the model is zero). The deterrence parameter, used in the model, was taken as the direct distance between the settlements, (Mahendru et al. 1985) and the one obtained from basic connectivity matrix (Srivastava 1989), which is not true for the new road links in erratic topographical conditions. The existing primary and secondary road systems were not taken as the framework in planning the

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rural roads and therefore, the possibility of connecting the settlements directly to these roads was completely ignored.

Kumar et al. (1997) suggested facility based approach for rural road planning. The road network was developed by connecting settlements to the nearest market in such a manner that maximum number of educational institutions fall along it. Although, in this study, the trip pattern of rural area was captured precisely, it was not used effectively in the network planning. The existing accessibility pattern of already connected settlements was extrapolated to the unconnected one in developing the linkage pattern. The total access needs of unconnected settlement due to its missing functions were not considered in developing the network.

Kim and Chung (2001) proposed measuring accessibility in terms of disutility index for spatial location - allocation of multiple centre villages using rural roads. The location-allocation method optimizes some functions of access to the facilities but it does not provide accurate information needed for improving or ranking the road linkages between settlements.

The Road Development Plan Vision: 2021 (IRC 2001) proposes the long term strategy for planning rural roads in India. It emphasizes preparation of master plans for rural road network in each district and building up from block level-needs. The road alignments should be optimized to serve maximum population and utilization of existing tracks including those constructed under different rural development programs. Due consideration should also be given to the improvement of existing fair-weather road to all-weather standards and to provide adequate cross drainage structures wherever these are missing.

Ministry of Rural Development (MORD) in India (MORD 2002) and World Bank (World Bank RT-4 2000) have suggested master planning rural roads based on the identification of core network, which ensures minimum connectivity for each village to a nearby main road or market center. The core network was identified through a rural road master planning process

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based on guidelines for preparation of ‘District Rural Road Plan’. This procedure is also adopted for planning and selection of through routes and link roads (Rao et al. 2007) under the Prime Minister's rural roads program (MORD 2002) in India. The drawback of this method is that core network is identified based on judgment on accessibility of settlements.

Rao et al. (2007) discussed about GIS based technique for identification of core network and rural road planning. Core network, consisting through routes and link roads, provides basic minimum access to all habitations with single all weather connectivity. Through routes were identified as road opening up large rural area, inter connecting two market centers/ towns, linking two major roads or interconnecting a long chain of settlements. Minimum spanning tree procedure is adopted for identification of core network. The efficiency of core network and link roads in meeting the access requirements of connecting settlement is not explained.

Anjaneyulu et al. (2007) presented methodology for planning rural roads based on secondary data sources. The road network was planned based on functional dependencies of settlement and potential interactions resulting from them. The developed network was evaluated using structural properties of the network. In this approach also the accessibility needs of the settlements were not considered in developing the network. In the planning process the cost of construction/upgradation of road links and their actual alignment were not considered.

Misra (2008) proposed inter-settlement interaction and functional accessibility approach for rural road network planning. In the proposed model prioritization and ranking of settlements for rural road connectivity was based on their population size and socio-economic status. An index parameter was developed for the settlements which reflects the importance or deprivation of the habitation and helps in selecting the target habitations for connectivity. For selecting the suitable road link among available link options, which provides connectivity

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to unconnected settlement, the accessibility benefit concept was used. The accessibility benefit offered by a route was directly related to the functional capacity of the joining area and indirectly related with the spatial distance between connected and unconnected habitations.

APPROACH TO RURAL ACCESS PLANNING

There is a strong interrelationship between travel and transport characteristics and primary and basic access needs of rural population. The factors effecting rural transport are, therefore, interactive and cannot be considered in isolation. An integrated approach is needed for effective accessibility planning to ensure that all the relevant factors and their interaction are properly taken into account. It should define the internal system and the external system that influences them.

The internal system should cover an appropriate geographical area encompassing interlinked settlements matching with planning objectives. The distribution of settlements should be shown together with the facilities to which they need access. Main access routes should be marked together with brief notes on their nature and any particular features, including seasonal variations. External system should cover all routes, major rural centers and facilities to which the internal system needs access or could benefit from access.

Formulating a system enables all the elements influencing accessibility needs and their interaction to be clearly identified and visualized. Interaction, i.e. the changes in one element of the system relates to and impact on other element. Considerable effort is needed initially to setup the system because of the substantial volume of local data which has to be collected and collated. However, once set up it provides a clear overall visualization of access needs and

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problems in the area and sound base for planning, ensuring that all relevant factors are included. The system can be readily updated to provide an ongoing means of recording the impact of interventions that have been made and for planning for further improvements in accessibility.

INTERVENTIONS FOR RURAL ACCESS PLANNING

The key aim of planning for rural access and development is to use limited resources in the most cost-effective manner, addressing priority needs and benefiting the maximum number of people. Access in rural areas can be improved in following three fundamental and complementary ways:

- through a better sitting of basic facilities and services that rural people need to use (water supplies, schools, health centers, markets); and
- through improving the mobility of rural people so that they can travel faster, easier, more convenient and less expensive (rural roads, tracks, trails, footbridges, waterways); and
- through promoting and stimulating the use of communication technology so that rural people have improved access to information related to health, education and market prices (rural telephones, e-mail and internet connections).

The first is a "non-transport/non communication intervention", the second is a "transport intervention" while the third is a "communication intervention". Following are the various ways through which transport interventions can improve rural accessibility:

- development of new road links in the network;
- improvement of existing rural roads including paths, tracks and footbridges;
- development of transport services

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- increased use of Intermediate Means of Transport (IMT)

The majority of communities in developing countries are reliant for access using paths, tracks or rural roads which are largely un-engineered and, mostly, not maintained. Rough and narrow roads and tracks not only increase travel time and cost, but also prevent or discourage their use by traders and transport operators due to the risk of getting stuck or damaging their vehicles. The lack of bridges or safe crossing points is often the main reason for rural communities becoming totally out of periods of time in the monsoon or rainy seasons. The accessibility in rural area can be improved by adding new road links or improving the existing rural roads, paths, tracks etc. for the development/improvement of road network. Effort involved in transportation may be reduced by improving the road infrastructure. It makes transport of goods easier by encouraging more efficient means of transport or replacing human effort with animal or motorized power. The benefits gained from these improvements result in enhanced capacity to transport greater loads over greater distances (Blokhuis 1996). The economic returns for local rural road infrastructure construction tend to be high particularly when opening access to an area.

NETWORK PLANNING METHODOLOGY

In most developing nations, due to wide variation in socio-cultural and geographical distribution of human settlements, development of optimal network within the available tracks, paths and roads to provide connectivity among the settlements has become necessary. The existing methods of rural road planning are based on broad guidelines for prioritization of road links and settlements to be connected. These methods, therefore, need further strengthening and quantification of the roads linking a settlement in a systematic way.

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From network planning point of view, rural roads in developing nations can be broadly classified into two categories i.e. internal road system and the external road system. The internal road system provides access to various subsistence needs such as firewood collection, drinking water, grinding mill, agricultural farm etc. These access points are largely located within and/or around the boundary of the settlement which is mainly the area encompassing habitat and agricultural fields of the settlement. The external road system is used to access facilities/ functions which are mainly available outside the settlement. Some of these functions may be educational institutions, market centers, hospitals, banks, post offices etc., depending on the development level of the settlement. Unconnected settlements which are poorly developed have greater dependence to other settlements/ locations in their neighborhood where these functions are present. The network planning methodology, presented in this research, is to plan for the external road system. The aim of planning this road system is to connect the rural settlements with existing roads in such a manner that the accesses to the facilities, goods and services that rural communities need for their social and economic development are met efficiently. The unconnected settlements need to be connected with at least one all weather road type to the existing regional roads so that it can have access to all its missing functions (IRC 2001). It will remove the isolation of settlements by connecting them to the existing main road network and thus to the main stream of the nation.

For planning this system of road network the use of conventional transport planning process, which is based on the principle of subdividing the study area into smaller zones and subzones and studying the interzonal trip frequencies through OD matrix to decide linkage needs between various origins and destinations, are not of much use. Even planning rural roads at the district level, there will be around 1500 to 2000 rural settlements and it will

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require enormous amount of resource to collect trip frequency data for all the settlements to form the O-D matrix. Even if, the O-D pattern is made available at the cost of huge amount of resources, the observed trip frequencies will be very low and that would hardly justify the links in the network. The use of such data will be only to fix the relative priorities of the linkages (Mahendru et al. 1985).

The rural road network needs to be developed so that the travel requirements of people or community are met to the maximum in a collective way at the lowest cost of road development. In other words, the developed linkage pattern of rural roads should provide maximum accessibility to the unconnected settlements. The aim of this research paper is to develop planning methodology for rural roads which maximizes the accessibility gains of the rural community as a whole. The system of roads connecting settlements may be an all together new construction or the upgradation of existing un-engineered paths, tracks or fair weather roads to an all weather road type (IRC 2001). Since all the paths, tracks and roads cannot be upgraded to the desired level for providing connectivity, therefore, there is a need to select the most efficient network which provides minimum basic access to all the settlements. In order to evolve this network its links should be evaluated for their efficiency in terms of the level of accessibility provided to the connecting settlement. The accessibility provided by a connecting road link to a settlement is inversely proportional to the total amount of travel required for satisfying the missing functions in the settlement. The total travel can be computed mathematically by identifying various missing functions, per capita trips for these functions, location of functions in the region, length of connecting road link and the population of the settlement. Total travel through the connecting road link is the summation of travel, in terms of person-km, for various missing functions in the unconnected settlement. Lesser the amount of travel required more accessible will be the settlement. Using this procedure, the road link offering maximum accessibility for each unconnected

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settlement can be determined. The network developed, based on person-kilometre as the only criteria, seems to evolve maximum accessibility connectivity pattern for unconnected settlements. But, this as the only criteria does not determine the order in which the settlements should be provided connectivity in the development of network. In other words, the settlements should be connected one at a time by considering and evaluating all the possible road link options in an orderly manner. If this order is not taken into account then the possibility of inter connectivity among various unconnected settlements gets ignored. This limitation can be removed by designing a new indicator of accessibility obtained by dividing the total person-km of travel with the population of the unconnected settlement. The indicator now represents the average person lead for an unconnected settlement to access all its missing functions through the connecting road link. It can be used to compare the accessibility offered by various connecting road link options and the one which offers the maximum accessibility should be chosen first in the process of network development. The mathematical formulation for this index of accessibility is discussed in the subsequent section.

DESIGN OF ACCESSIBILITY INDEX

In rural road planning, the road links are added to the existing network of primary and secondary road system so that each unconnected settlement gets connected through at least one road link of all weather road type. The connecting road link, emanating from the unconnected settlement, either joins a nearby connected settlement or to any intermediate node on the links of the existing road network. Therefore, the entire system of nodes, in rural road planning process, can be divided into two categories, i.e. unconnected nodes (settlements) and connected nodes (i.e. connected settlements and the suitably spaced intermediate nodes on the links of the existing road network). A link option is a road link between the unconnected and connected nodes. A few such link options are shown in Fig. 1. Apart from these link options the settlement can also be provided connectivity by upgrading the existing paths, tracks and un-surfaced roads through which the settlement is already connected with the existing road network.

If the total number of connected nodes in the existing road network is `m' then, theoretically, there will be these many link options offering connectivity to each unconnected settlement. However, many of these link options will be redundant as they will be intersecting the existing road network at many points and excessively large in length. Among these link options one which offers maximum accessibility to the unconnected settlement should be chosen in the development of rural road linkage pattern. The accessibility of a link option can be calculated by identifying the missing functions (k) in the unconnected settlement, the total travel requirement of the unconnected settlement (PK) in terms of person-km to satisfy all its missing functions and the length of new road link option (d) as given below.

The total person–km of travel i.e. $PK_i^{(l)}$, for an unconnected settlement `i' to access missing functions 'k' through the link option `l' can be calculated from Eq.(1).

$$PK_i^{(l)} = \Sigma_k T_i^k \cdot d_i^{k(l)} \quad (1)$$

Here, T_i^k is the total number of trips originating from unconnected settlement `i' to access missing function `k' and $d_i^{k(l)}$ is the distance between the unconnected settlement 'i' to the nearest function `k' through the link option 'l'.

The $d_i^{k(l)}$ can be calculated using Eq. (2).

$$d_i^{k(l)} = d_{im}^{\ l} + d_{mj}^{\ k} \quad (2)$$

Here, $d_{im}^{\ l}$ is the length of link option 'l' (i.e. the ground distance between the unconnected settlement 'i' and connected node 'm' on the network) and $d_{mj}^{\ k}$ is the minimum distance between node 'm' and the nearest node 'j' on the network where the function `k' is present. If the function `k' is present at node 'm' then $d_{mj}^{\ k}$ will be zero.

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The accessibility index of link option `l' (i.e. A_i^l) is calculated by dividing the total person- kilometre '$PK_i^{(l)}$' with the population of the settlement (P_i) as given in Eq. (3).

$$A_i^l = PK_i^{(l)} / P_i \qquad (3)$$

Here, P_i is the population of the unconnected settlement 'i' .

In this computation of accessibility it is assumed that the unconnected settlement access the first nearest function in its neighbourhood, through the link option, to satisfy its missing functions. Higher value of A_i^l indicates lower accessibility of link option (l), and vice-versa. In physical sense A_i^l represents average lead distance of population to access all the missing functions in the unconnected settlement when it gets connected through the road link (l). The link option with minimum index value (i.e. maximum accessibility) is the most preferred choice in developing the maximum accessibility network.

The estimation of accessibility index, using Eq. (3), requires the determination of T_i^k and $d_i^{k(l)}$. 'T_i^k' can be estimated by multiplying the settlement size (P) with the appropriate trip rate (t^k) for each function, as given in Eq. (4).

$$T_i^k = P_i \, . \, t^k \qquad (4)$$

Here, the settlement size P_i may be the population, number of households etc of settlement `i'. and the trip rate ($t^k$ ) represents trips per unit settlement size for missing function `k' in the unconnected settlement.

For rural areas, appropriate trip rate models can be developed by correlating it with the socioeconomic factors. The model form can be represented as shown in Eq. (5).

$$t^k = f \text{ (socio economic factors)} \qquad (5)$$

In absence of any such model at the moment, t^k can be easily estimated for a few of the functions. For example, if the entire rural population is to be provided education up to High school standard by the end of planning horizon then the trip rates to primary, middle and high school will be nothing but the proportion of the school going population in their

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corresponding age groups. However, the trip rates for marketing, health purpose etc will depend on the expected level of development in the area. These trip rates will be less in underdeveloped areas and more for the developed areas.

The term $d_i^{k(l)}$, has two components i.e. d_{mj}^k and d_{im}^1, . Here, the term d_{mj}^k can be estimated quite easily, as the location of facilities on the existing road network is known. The other term d_{im}^1, which is the length of new link option, will depend on its actual alignment on the ground. This alignment need not always be a direct one and will primarily depend on the topography of the area. Topographic features such as water bodies, hills, costly structures, land type etc may cause deviation from straight alignment. Even for the network planning of a small number of unconnected settlements there will be many possible road link options and their alignment, depending on topography of the area. These link options needs to be analysed for their alignment, length, construction cost etc so that the least cost options could be selected. It will be difficult to analyse these alignments manually or by any other method, particularly for erratic terrain conditions. However, the spatial analysis tools available in GIS can be used innovatively to determine the least cost alignment between any two points in the area. Therefore, in the present research, the entire data is organised at the GIS platform first and then it is used for the alignment of new road link options and planning the rural road network in an integrated manner. These are discussed in the subsequent sections.

DEVELOPMENT OF GIS DATABASE

Accessibility based planning of rural road network requires a comprehensive information system consisting details about location of the settlements, facilities and services, system of road network which brings them together, and demographic, socio-economic and topographical characteristics of the region. Geographic Information System (GIS) technology

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provides a new paradigm to organize and design the information systems for such application. At GIS platform, the database, particularly the road network related one, gets easily extended by integrating many sets of its attribute and spatial data. Moreover, it also facilitates integration of all the socio-economic data with road network database for a wide variety of planning functions. And, the beauty of this tool is that it allows a stage development approach in building of the database itself.

A GIS database is made up of two parts i.e. spatial (map) data and nonspatial (attribute) data. The spatial data is in the form of digital map, which is organised as layers in GIS. The attribute data is mainly the numeric and character data of these layers. To develop the GIS database for rural road planning, the entire data can be classified into four categories i.e., settlement, road network, topographic and land type. The spatial data should consist of map layers of settlements, different types of road network, topographic features such as water bodies, drainage lines and hills, and land type such as agricultural, marshy and barren lands etc. The attribute data should consist of demographic details, socio-economic functions/ facilities and per capita trip for each function. The road attributes should consist of information about road and surface type, geometry, pavement condition, soil and terrain type. The road network information should consist of all the existing alignments of paths and tracks of any form, which can be the potential link option in developing the rural road linkage pattern. The drainage layer attribute should consist of its type, such as rivers, major and minor drainage lines etc, which is useful in determining the type of cross drainage structure to be constructed wherever the road alignment crosses it. The attribute of land type layer consist of information about land determining its acquisition cost.

The Paithan taluka (an intermediate tier of administrative unit within a district) of Aurangabad district in Maharastra state in India is taken as the study area to develop the GIS database and to implement the developed rural road planning methodology. The GIS database

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consist all the data items, as discussed above, except the land type data, which was not available for the study area. The GIS software package ‘TransCAD’ from Caliper Corporation, USA, is used to organise the data and implement the rural road planning methodology. The network and spatial analysis modules, available in the TransCAD software, are used to extract various input data items required for planning. The map of the study area, prepared using the developed GIS database, is shown in Fig. 2. GIS database is used to identify the connected and unconnected settlements, estimate travel requirement, distance of facilities/function and the alignment of various link options. The framework for GIS database development and its integration with rural road planning process is depicted in Fig. 3. The procedural steps to extract various input data items needed for rural road planning in the context of study area are discussed further in the subsequent sections.

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Connected and unconnected settlements

Paithan taluka consists of 179 settlements (villages) and well-developed network of all three levels of road i.e. primary (Major State Highway and State Highway), secondary (Major District Roads) and tertiary road system (Other District Roads and Village Roads). Taluka is an intermediate tier of administrative unit in between the village and district in India. There are no National Highways in Aurangabad district therefore the important State Highways of the district are represented as Major State Highway by the Public Works Department. The methodology, developed in the present study, evolves the rural road network in the framework of existing primary and secondary road system. The settlements of Paithan taluka are first, classified as connected and unconnected with respect to this primary and secondary road system.

It can be observed from Fig. 2 that most of the settlements in Paithan taluka are connected through some form of rural road. In order to implement and test the rural road planning methodology, developed in this research, the existing rural roads in the area were taken as non existent. It has two advantages. Firstly, it increased the number of unconnected settlement in the study area. Secondly, network planned using accessibility criteria can be compared with the existing network of rural roads in the region.

The unconnected settlements are identified by querying the point layer of settlements for their distance from the existing primary and secondary road system in the study area which consists of Major State Highway (MSH), State Highway (SH) and Major District Roads (MDR). Settlements less than 0.5 km distance from these roads are treated as connected and rest all are taken as unconnected. This criterion is necessary, as all the connected settlements need not be exactly located on the road network. The connected and unconnected settlements with respect to the existing MSH, SH and MDR road network in the area is shown in Fig. 4.

Travel requirement of unconnected settlements

The travel survey, conducted in rural area in India, revealed that nearly 50% of the rural population is static i.e., it does not make any trip (Kumar 1997). The trip percentage in rural settlements in India, classified according to their purpose, is shown in Fig. 5. It was observed from these surveys that, the highest number of trips in rural areas is for education (42 %) and about 86 % of trips, other than educational trips, terminate to the nearest market center. The trips terminating either to the market center or to the educational institutes constituted 93% of the total trips. It can, therefore, be concluded that the majority of travel in rural area is either for marketing or for educational purposes. Access of rural population to health services is also important, and therefore, it should be included in assessing the overall travel requirement of the settlements. Three main trip purposes (functionalities), therefore, identified in the present research to estimate the total travel requirement of rural settlements for a typical Indian rural settlement are marketing, education and health. These are typical to the travel

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characteristics and requirement of rural people in India. However, there can be area specific travel requirements, such as travel for industrial work place, collection of potable water in arid zones, etc that can also be considered for the assessment of total travel requirements of unconnected settlements.

After the identification of the functions, to which the rural settlement should be provided access, the potential trips for each function are determined by multiplying the settlement population with the corresponding per capita trip rate. The per capita trip rate to school of a particular education standard (such as primary, middle and high school) is taken as the proportion of school going population of that education standard. The market trips are calculated using the actual trip rate to the market centers, obtained from the rural travel data reported in literature. The trip rate for health purpose, which was not available, has been suitably assumed. Various per capita trip rates, used in this study, are given in Table 1.

Distance of facilities from settlement

In order to assess the total travel need of each unconnected settlement using Eq. (1) the distances of various facilities from each unconnected settlement should be estimated. Those facilities which are present in the settlement, their distances are zero. A module is coded to locate the nearest facility, using existing network of primary and secondary road system, for each settlement. The inputs to this module are the shortest path distances between settlements and the location of functions in the settlements. These distances are estimated using the shortest path module, available in TransCAD.

Alignment of link options

One of the main objectives of road planning is to minimize the construction cost of road links in the developed network. This requires that the construction cost of all the possible

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connecting link options should be estimated so that it can be used during the network planning process. The construction cost of a road link depends mainly on its alignment, which is governed by the topography of the area. In order to minimize the construction cost of new road links, there should be minimum natural barriers like rivers, hillocks, ponds, lakes etc along the alignment. In addition, the land acquisition cost, if any, should also be minimum. The link options of higher construction cost should get lower preference in the network development process. However, it is difficult to determine the least cost alignment manually, considering various topographic factors in the region. For a set of 'n' settlements, theoretically, there will be n(n-1)/2 number of possible direct links options of inter-settlement connectivity alone. Even for a small value of 'n' there will be many link options that should be explored. In the present research, therefore, a GIS based methodology is developed to compute construction cost of each alignment and determine the least cost road alignment. This methodology is based on grid network analysis concept, using vector data, developed in the present research and implemented in GIS using its network and spatial analysis functionalities. The method consists of overlaying the entire study area with small size grids. The grid layer is then spatially queried with each layer of topographic feature. After this query, each element of the grid layer gets loaded with the topographic information of the area. The total road construction cost along each link of the grid element is then computed using this information. The shortest path principle, taking the construction cost as the link attribute of the network, is used for the alignment of link option between any two points in the area. The accuracy of road alignment depends on the size of the grid. Smaller the size of grid element, more accurate is the alignment. However, for small size grid the network becomes large, which requires more computational power. This methodology therefore, operates on the vector data, which is more efficient and different from earlier raster based

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approaches of road alignment developed in GIS. The alignment of link options in context of rural road planning is explained further, as given below.

As shown in Fig. 1, an unconnected settlement can be provided connectivity either by connecting it with an already connected settlement, or by connecting it with the nearby road. Therefore, for rural road planning all the possible link options can be categorised into two heads, i.e. the one between unconnected and connected settlements and other between unconnected and the intermediate nodes on the nearby links of the existing primary and secondary road system. To analyse the connectivity through intermediate nodes, existing road links are broken to small segments by inserting intermediate nodes. A separate module is developed, to create intermediate nodes at specified distance (in the present case study it is at every 200 m interval) between the end nodes of the road links in the existing network. Another module creates square shape grid, of specified size (in the present case it is 1 km) with intersecting diagonals, over the study area. The square grid layer is then merged with the existing road layer. Connectors are drawn from the point layer of unconnected settlements to the merged layer of road and grid. The combined layer of grid, road and connectors is then queried with the drainage layers of major and minor rivers, canals and other drainage lines in the area. The number and type of cross drainage structures required along each element of the combined layer thus gets identified. The construction cost of each type of cross drainage structure, in terms of equivalent road length, is then added to the actual length of the link of the grid, which gives the total cost of road construction for each grid element. Since the information about the width of drainage line is not available in the present information base, therefore, the construction cost of major bridges, minor bridges, other cross drainage structures and canal crossings are assumed equivalent to 20 km, 5 km, 0.5 km and 2 km of construction cost of new road length respectively. However, if the average width of drainage lines is available then the span at cross drainage structures can be calculated through quarry

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procedure in GIS and their cost of construction can be obtained more realistically. The network of grids, with the link attribute as its construction cost, is now used to determine the least construction cost alignment, using shortest path principle in GIS.

NETWORK GENERATION PROCEDURE

The necessary inputs to rural road network development have been discussed in the previous sections. The primary and secondary road system is taken as the existing regional roads of the area and new rural road links are added to it in a prioritized manner. The link options can be either a completely new road alignment or the existing paths and tracks in the area. The road network data of study area did not have the alignment of existing paths and tracks, and therefore, these alignments are not included in this case study. The flow chart of rural road network generation, using accessibility criteria, is shown in Fig. 6, which is implemented in the GIS software package, TransCAD. In this figure various inputs to compute the accessibility index of a link option are shown. The accessibility model takes each unconnected settlement at a time, considers all its connectivity options (i.e. connectivity with an already connected settlement or to the existing nearby road), and calculates their accessibility index. For each unconnected settlement, the link option with minimum index value (i.e. maximum accessibility) is identified. This process is repeated for all unconnected settlements. All the link options of various unconnected settlement are now compared for their accessibility index values. The link option having minimum accessibility index value and its corresponding unconnected settlement thus gets identified. The first priority rural road link, that should be added to the existing network of regional road, along with the settlement, that should be connected, thus gets identified. The list of connected and unconnected settlements and the existing road network is updated at this stage. The newly connected

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settlement now offers the functionality present in it to other settlements in its neighborhood, which can be accessed through the updated network. Therefore, the distances of facilities from connected settlement are also updated. At this stage, there are some more new link options between the newly connected settlement and the remaining unconnected settlements in its vicinity, which should be evaluated for their accessibility. For remaining unconnected settlements, the link options of minimum index value (i.e. maximum accessibility) are identified. The accessibility index of these new link options is calculated and then compared with the previously stored accessibility values of the link options for the remaining unconnected settlements. Those unconnected settlements, which have less accessibility index value, through these new link options, are updated with the new link options and their index values. Again, the link option of lowest index value and its corresponding settlement is identified. This identifies the next link option that should be added to the road network in the development of linkage pattern. This process is repeated till all the settlements get connected.

The maximum accessibility network generated for the study area, using this procedure, is shown in Fig. 7. The existing rural roads (i.e. ODR and VR) in Paithan Taluka, which have developed over time, are also shown in this figure as double line filled with gray colour and the road links generated using accessibility criteria are shown with black color thin continuous line. Wherever the generated road links matches with the existing rural roads they overlap. It can be observed that, all the unconnected settlements got connected with only one road link, which offered maximum accessibility to the settlement. The road segments in the existing rural road network which are not important from accessing the missing functions of unconnected settlement can be identified from the figure. However, these road segments can be important for interaction between settlements other than the missing functions. In Fig. 7, the road segment between settlement number 804 and 823, shows such type of existing rural road link. It can be also observed that the unconnected settlement number 832, which is very

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close to the existing primary and secondary road system, has a direct road connectivity with it. The settlement number 878 has a direct connectivity with connected settlement number 785, which is a new road link, aligned using grid network analysis technique. The network thus generated has both type of road links, i.e. the direct road links connecting to an already connected settlement and the road links connecting to the nearby existing primary and secondary road system.

It is possible to generate other type of rural road networks by modifying the link selection criteria. Construction cost is taken as the other criteria to generate the minimum construction cost rural road network for the same study region. In this case, the accessibility is not required to be calculated. So, there is no need of inputs, such as distance of facility from the connected settlement and travel requirement of unconnected settlement. Minimum accessibility index value criteria for selecting the link options is replaced with the minimum construction cost criteria. The minimum construction cost network thus generated, has the minimum road length to connect all the settlements. To compare the minimum construction cost network with the maximum accessibility network, the characteristics of both networks are summarised in Table 2. In this table, the person-km represents the total amount of travel needed to access the missing functions in the unconnected settlements and the cost represents the total construction cost of rural roads in terms of equivalent new road length in km. It can be observed from the table that, the minimum construction cost network involves more amount of travel to satisfy the missing functions of unconnected settlements in comparison to maximum accessibility network. In other words, the maximum accessibility network is more efficient in comparison to minimum construction cost network in accessing the missing functions in the settlement. Therefore the connectivity of rural road should be developed using accessibility criteria rather than the minimum construction cost criteria. This network of rural roads will be thus more economical in long run.

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CONCLUSIONS

A well planned road system is one of the most important infrastructure elements which improves rural accessibility and contributes to the rural development as a whole. The rural road network in developing countries, therefore, needs to be developed so that the travel requirements of people or community are met to the maximum in a collective way at the lowest cost of road development. The unconnected settlements need connectivity with at least one all weather road type to the existing regional roads so that it can have access to all its missing functions. The planning methodology developed in this research is, therefore, based on accessibility concept and generates connectivity pattern for unconnected settlements. Each road link, identified at various stages of network development, is evaluated for its efficiency in serving the access needs of the connecting settlement. An index of accessibility is designed which evaluates a connecting road link for its efficiency in accessing the missing functions in the unconnected settlement. The rural road planning methodology is implemented in GIS software package, TransCAD, and all the data needed for planning is organised in it. The connecting road links for a settlement need not always have the straight alignment, as considered in most of the rural road planning methodologies. A new method is developed in GIS which finds least cost road alignment between any two points based on topographic information of the area. This technique is new and unique as it is implemented in vector based GIS. It is used to find the actual road alignment of link options and is used in network planning. Paithan Taluka of the Aurangabad district in India is taken as the study area for the implementation of the developed methodology. The network developed is compared with minimum construction cost criteria. It is observed that, the efficiency of network generated using accessibility criteria is more than the network generated using

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minimum construction cost criteria. The rural road network developed using accessibility criteria is thus more economical in long run and meet the travel requirement of settlement in the most efficient manner.

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APPENDIX-I. REFERENCE

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APPENDIX. II NOTATION

The following symbols are used in this paper:

i = unconnected settlement.

j = connected node (i.e. connected settlement node or the link nodes of the existing road network).

l = link option.

k = function to be accessed by the unconnected settlement.

$d_i^{k(l)}$ = distance of nearest function `k' from unconnected settlement ‘i’ through link option ‘l’.

d_{im}^{1} = length of link option ‘l’ between the unconnected settlement ‘i’ and any connected node ‘m’ on the network.

d^k_{mj} = distance between node ‘m’ and the nearest node ‘j’ where the function `k' is present.

A_i^l = accessibility index of link option ‘l’ for settlement `i'.

$PK_i^{(l)}$ = total person–km of travel for settlement `i' through link option ‘l’.

$T_i^{k(l)}$ = total number of trips originating from unconnected settlement `i' to access facility type `k' through link option ‘l’.

P_i = population/size of settlement 'i'.

t^k = trip rate for function `k'.

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Table

Table 1 Trip Rates in Rural Settlement

Trip purpose	Trip rate (trip/day/person)
Primary school	0.122
Middle school	0.072
High school	0.048
Marketing	0.133
Health center	0.03

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Table 2 Characteristics of Networks Generated

Network Generation Criteria	Person -Km	Total length of new links (km)
Accessibility	165128	607.38
Construction Cost	217758	350.26

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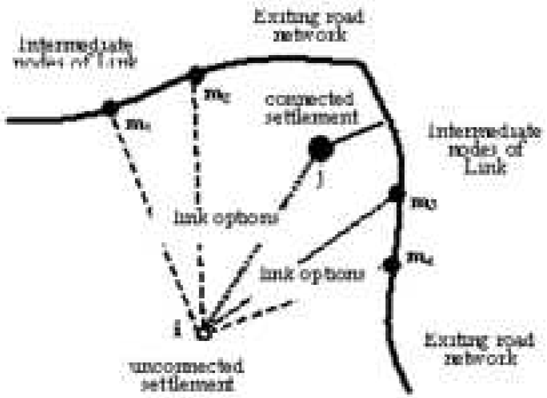
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Intermediate nodes of Link
connected settlement
j
Intermediate nodes of Link
link options
link options
i
unconnected settlement
Exiting road network

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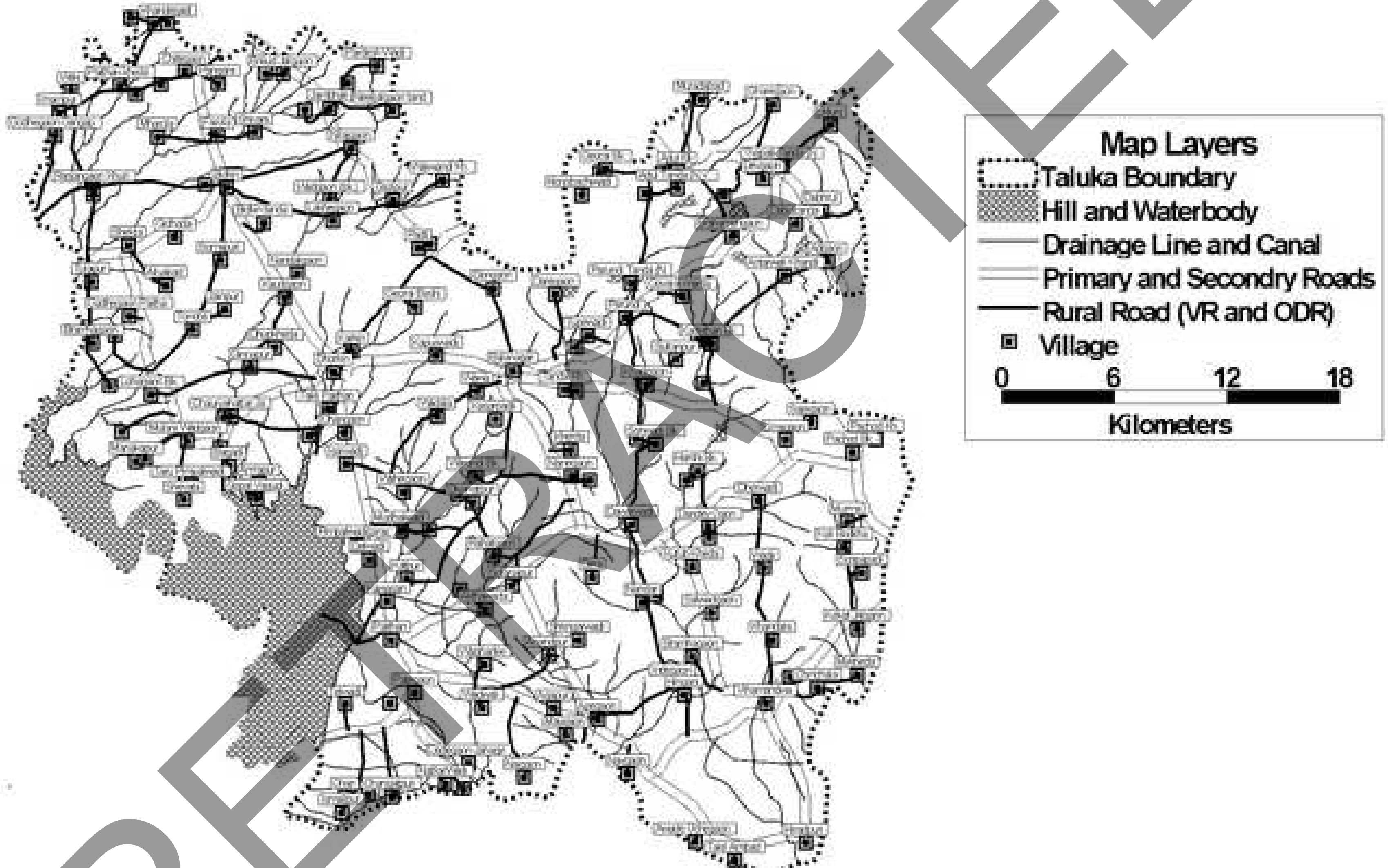
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Taluka Boundary
Hill and Waterbody
Drainage Line and Canal
Primary and Secondry Roads
Rural Road (VR and ODR)
Village
0
6
12
18
Kilometers

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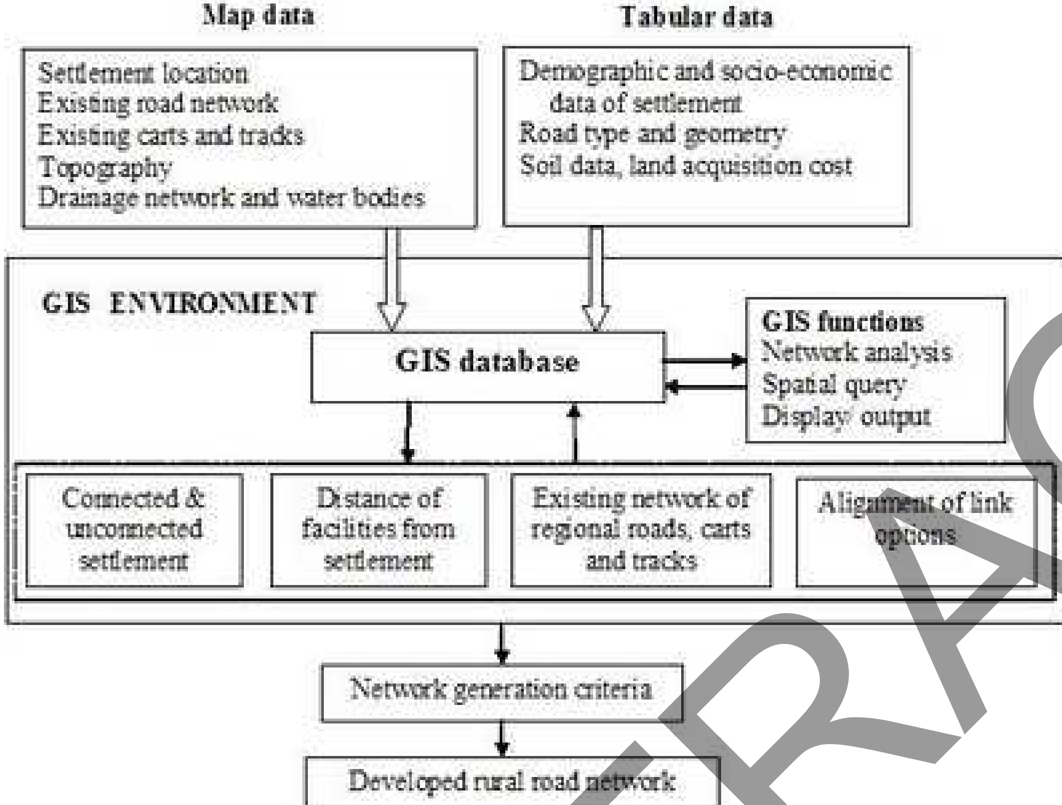
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Tabular data
Settlement location
Existing road network
Existing carts and tracks
Topography
Drainage network and water bodies
Demographic and socio-economic data of settlement
Road type and geometry
Soil data, land acquisition cost
GIS ENVIRONMENT
GIS database
GIS functions
Network analysis
Spatial query
Display output
Connected & unconnected settlement
Distance of facilities from settlement
Existing network of regional roads, carts and tracks
Aligament of link options
Network generation criteria
Developed rural road network

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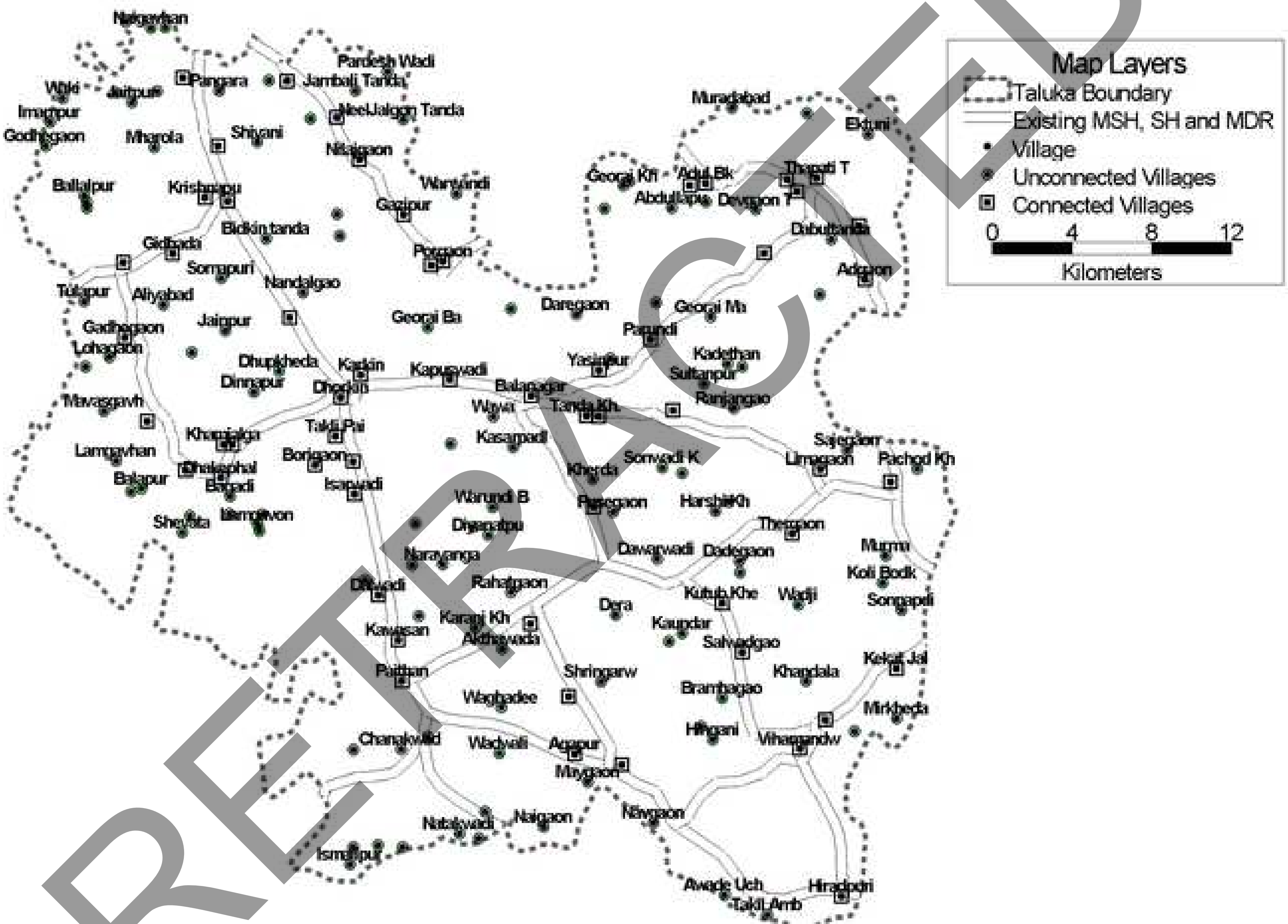
Map Layers
Taluka Boundary
Existing MSH, SH and MDR
Village
Unconnected Villages
Connected Villages
0
4
8
12
Kilometers
Pangara
Jambali Tanda
Shivani
Krishnapur
Ballalpur
Tulapur
Jaigpur
Nandalgao
Georai Ba
Daregaon
Kapusvadi
Balanagar
Kasamadi
Kherda
Sonvadi K
Ranjangao
Sultanpur
Kadethan
Georai Ma
Muradabad
Ekduni
Dadegaon
Dawarvadi
Rahatgaon
Narayanga
Kawasan
Paithan
Waghadee
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Wadwali
Maygaon
Navgaon
Naigaon
Awade Uch
Takli Amb
Hiradpuri
Vihamandw
Hingani
Brambagao
Khandala
Salwadgao
Kaundar
Dera
Kutub Khe
Wadji
Songapeli
Koli Bodk
Mirkheda
Kekat Jal
Pachod Kh
Limgaon
Thergaon
Harshi Kh
Lamgavhan
Balapur
Dhakephal
Borgaon
Isarvadi
Takli Pai
Dhorkin
Dinnapur
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Lohagaon
Gadhegaon
Aliyabad
Mavasgavh
Nilajgaon
Gazipur
Porgaon
Wanvadi

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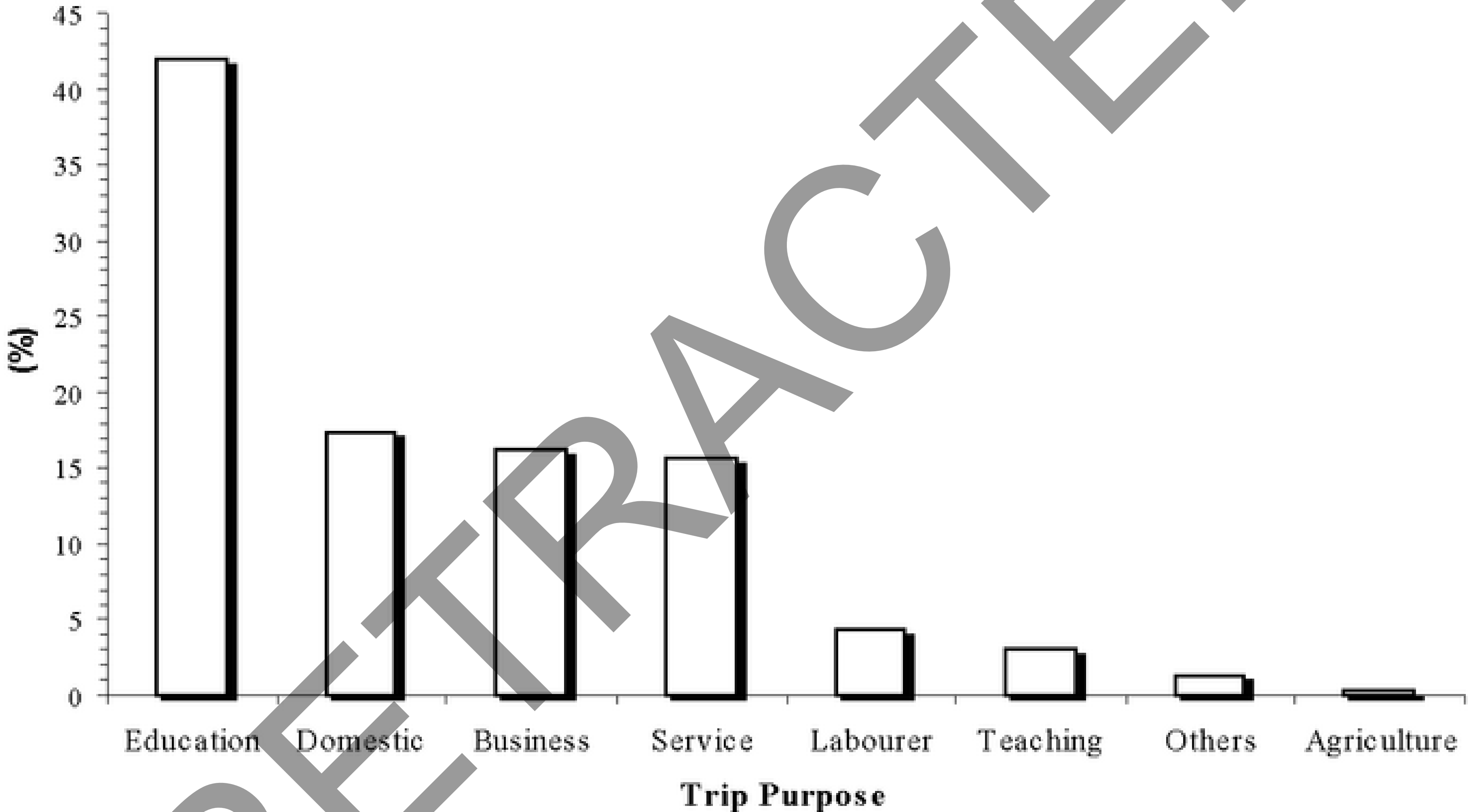

45
40
35
30
25
20
15
10
5
0
(%)
Education
Domestic
Business
Service
Labourer
Teaching
Others
Agriculture
Trip Purpose

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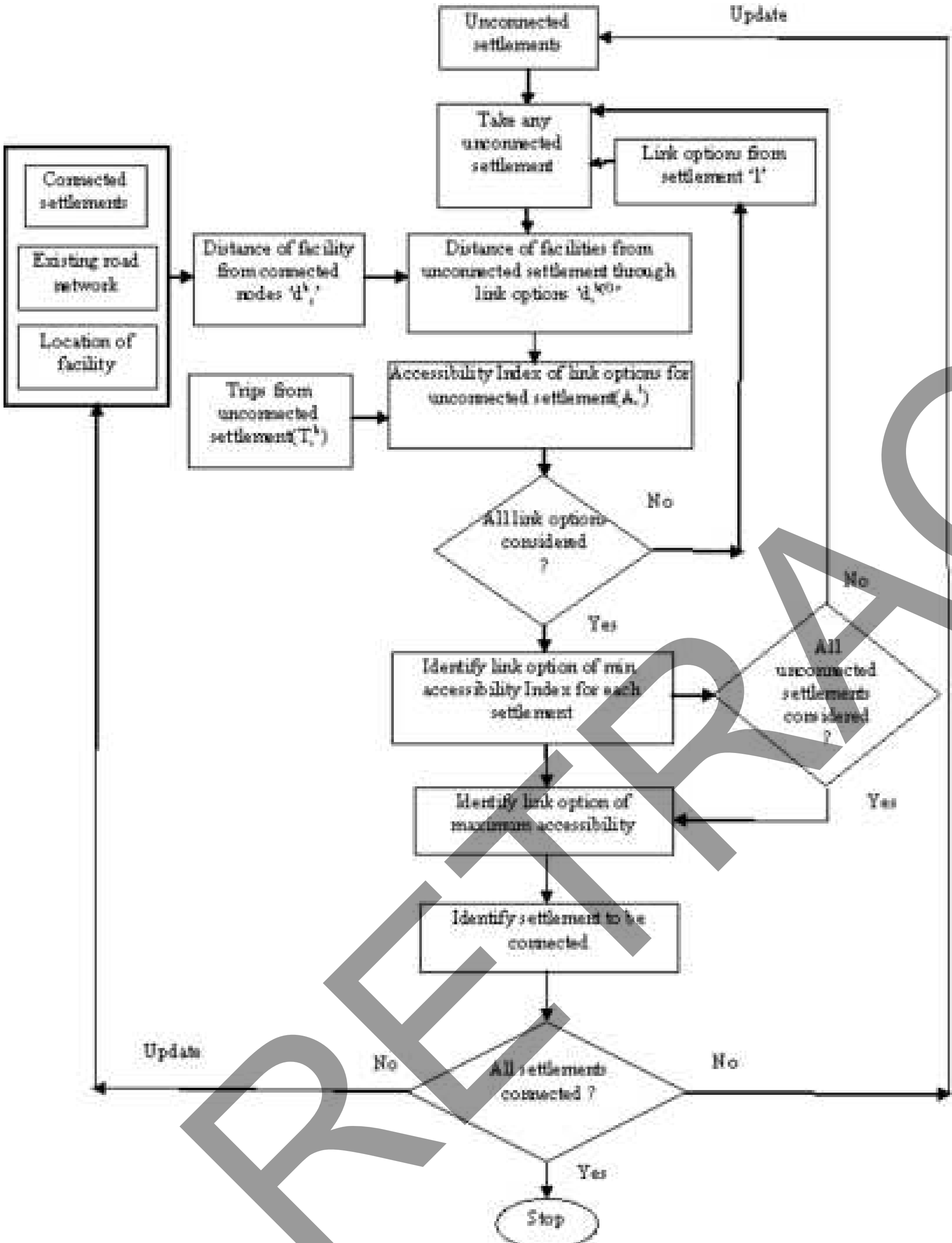
Unconnected settlements
Update
Take any unconnected settlement
Link options from settlement 'l'
Connected settlements
Existing road network
Location of facility
Distance of facility from connected nodes
Distance of facilities from unconnected settlement through link options
Trips from unconnected settlement
Accessibility Index of link options for unconnected settlement
No
All link options considered ?
Yes
No
Identify link option of min accessibility Index for each settlement
All unconnected settlements considered ?
Yes
Identify link option of maximum accessibility
Identify settlement to be connected
Update
No
All settlements connected ?
No
Yes
Stop

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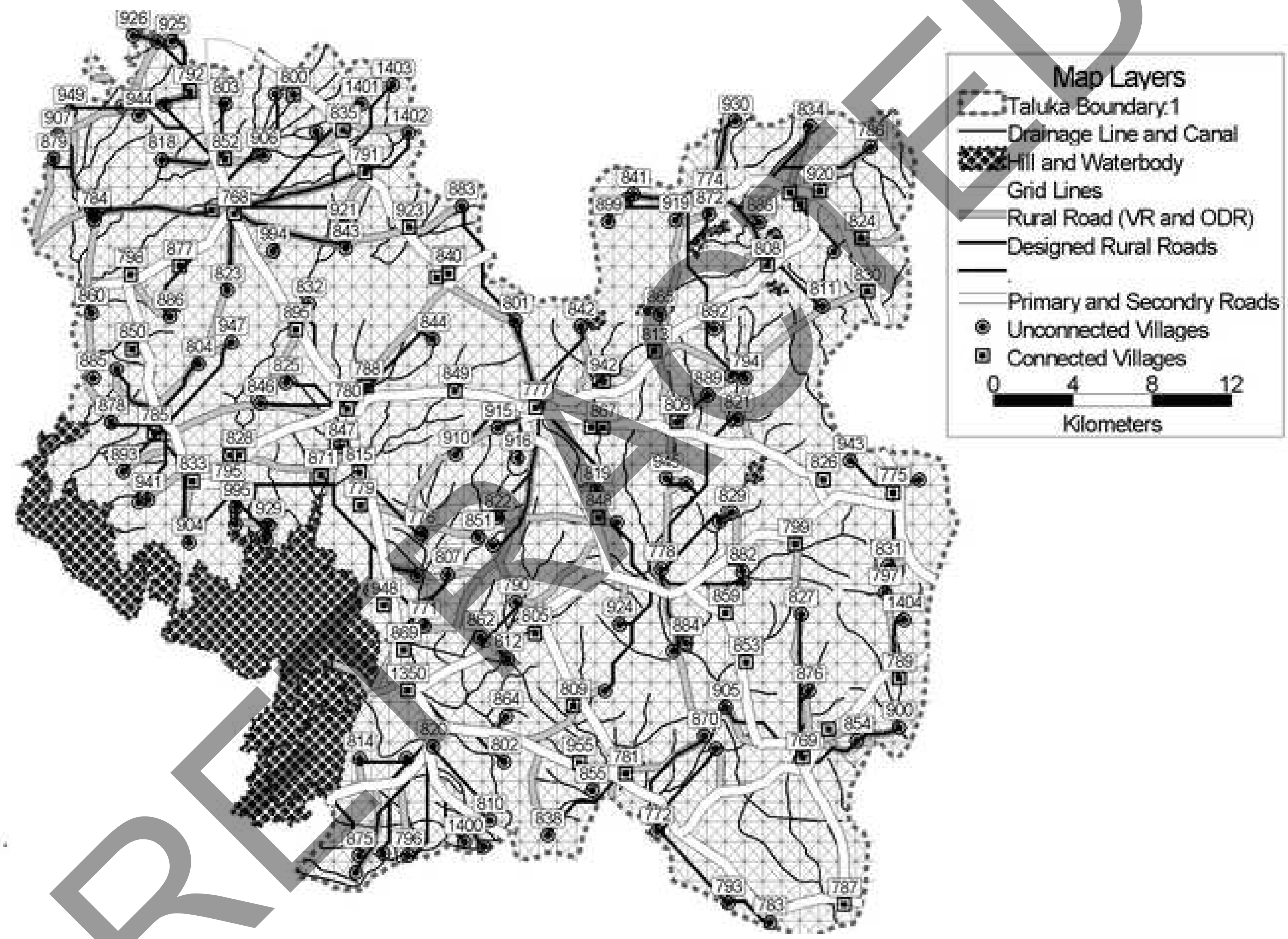
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Taluka Boundary.1
Drainage Line and Canal
Hill and Waterbody
Grid Lines
Rural Road (VR and ODR)
Designed Rural Roads
Primary and Secondry Roads
Unconnected Villages
Connected Villages
0 4 8 12
Kilometers

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Figure Captions

Fig. 1 Link options from unconnected settlement

Fig. 2 Map of study area (Paithan Taluka)

Fig. 3 Framework for GIS development and rural road planning

Fig. 4 Connected and unconnected villages

Fig. 5 Trip making characteristics in rural areas

Fig. 6 Rural road network generation using accessibility criteria

Fig. 7 Maximum accessibility rural road network

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