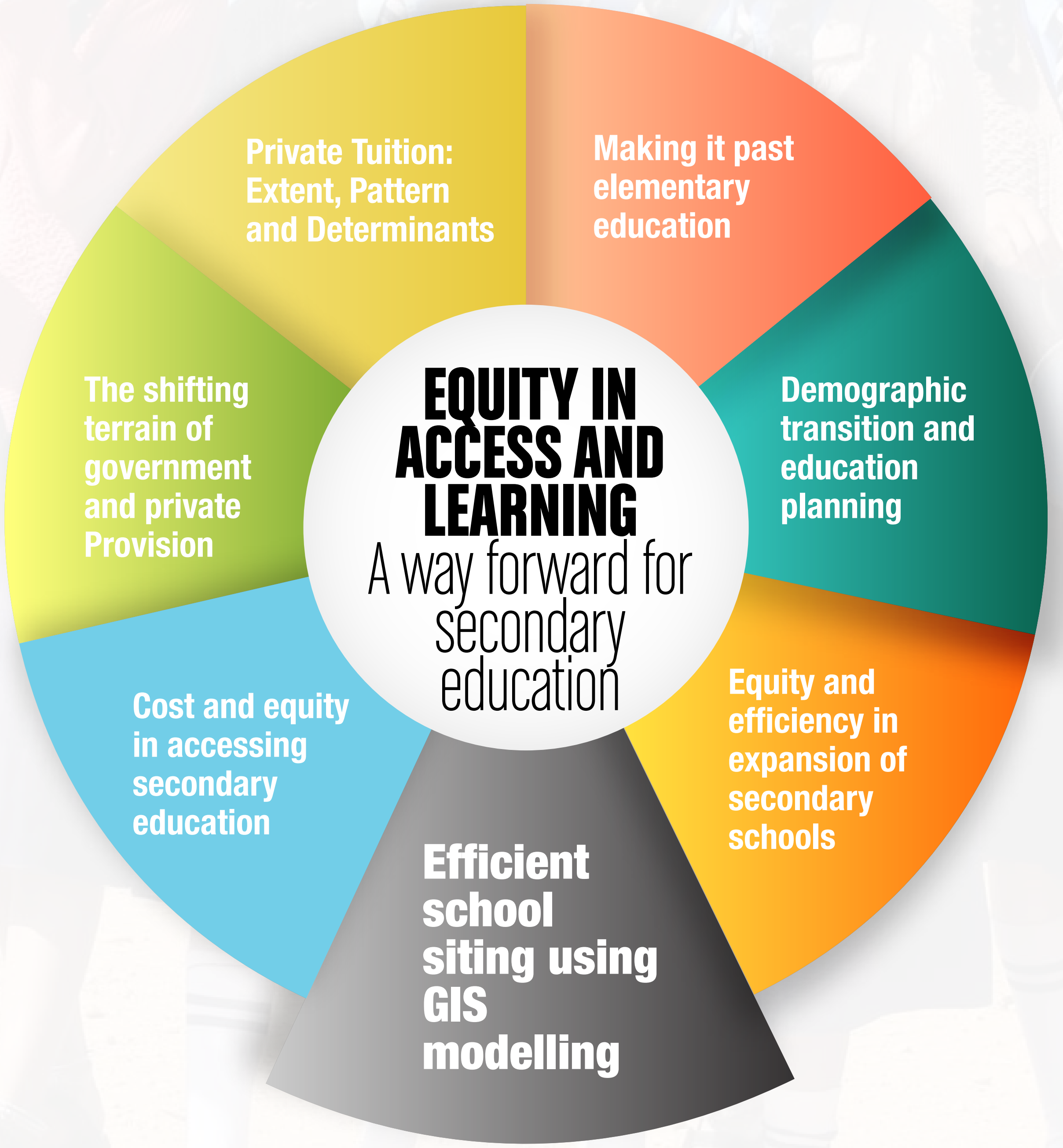
Government of India
Ministry of Human Resource Development

RESEARCH REPORT IV

Efficient School Siting Using GIS Modelling



RMSA-TCA
Rashtriya Madhyamik Shiksha Abhiyan
Technical Cooperation Agency

Preface

This document is one of a series of seven research reports which has been prepared to accompany the single consolidated recommendation report *Equity in Access and Learning: A Way Forward for Secondary Education in India*. The research reports are intended to be of interest to planners, managers and policy makers, as well as to academics involved in development of policies and plans for secondary education. In addition to these reports, a research priority framework and research quality assessment framework has also been developed to take this research agenda forward.

The research programme was developed by the Rashtriya Madhyamik Shiksha Abhiyan-Technical Cooperation Agency (RMSA-TCA) in discussion with National University of Educational Planning and Administration and the Ministry of Human Resource Development (MHRD). The research was developed to respond to concerns expressed in the Joint Review Missions (JRM) to strengthen the evidence base for diagnosis of issues arising during the implementation of RMSA, and to inform policy dialogues on options that could increase access, efficiency, effectiveness, and equity.

This research report, through application of Geographical Information System in one case study district in Assam, explores patterns of distribution of secondary schools in relation to population dispositions and its implication for efficiency in expansion. It models implications of optimal school location on distance to access these secondary schools.

The eight research reports in this series are as follow:

Research Report ***(Consolidation)***	**0:**	**Equity in Access and Learning: A Way Forward for Secondary Education**
Research Report	**1:**	**Making it Past Elementary Education**
Research Report	**2:**	**Demographic Transition and Education Planning**
Research Report	**3:**	**Equity and Efficiency in Expansion of Secondary Schools**
Research Report	**4:**	**Efficient School Siting using GIS Modelling**
Research Report	**5:**	**Cost and Equity in Accessing Secondary Education**
Research Report	**6 :**	**The Shifting Terrain of Government and Private Provision**
Research Report	**7:**	**Private Tuition: Extent, Pattern and Determinants**

RMSA TECHNICAL COOPERATION AGENCY

EFFICIENT SCHOOL SITING USING GIS MODELLING

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Note on Documentary Series

A series of documents has been produced by RMSA Technical Cooperation Agency for the Government of India's programme to make good quality secondary education available, accessible and affordable to all young persons in the age group of 14-18 years.

The documentary series is arranged as follows:

RMSATCA 0	Programme Management Reports and Documents
RMSATCA 1	National Achievement Survey (Reports and Documents for Thematic Area 1)
RMSATCA 2	Teacher Management and Development (Reports and Documents for Thematic Area)
RMSATCA 3	School Standards, Evaluation and Development (Reports and Documents for Thematic Area 3)
RMSATCA 4	Data Management and Use (Reports and Documents for Thematic Area 4)
RMSATCA 5	Results Focused Planning (Reports and Documents for Thematic Area 5)
RMSATCA 6	Research (Reports and Documents for Thematic Area 6)
RMSATCA 7	Communication and Knowledge Management (Reports and Documents for Thematic Area 7)

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Executive Summary

This research has undertaken a GIS based analysis of the following questions:

- How many secondary schools (along with their locations) will be needed if the plans are developed using school planning norms and what will be their respective school size over next 5-10 years?
- What are the implications of relaxing distance norms and using school size criteria to determine school location?
- What are the efficiency and effectiveness trade-offs associated with different methods of school siting?
- How can GIS information be used to optimise school resourcing for ensuring maximum efficiency?

Location-allocation analysis was used to determine the optimal locations of schools using different distance norms and optimality criteria. A total of three school size scenarios are modelled; schools of size 160, 340 and 520. For each scenario, two optimality criterion are examined: minimizing average distance of the secondary school age population in villages to the nearest school facility and, to maximize the secondary school age population covered with capacity constraints. For each criterion four distance norms are assessed: no distance constraint, 5 km, 10 km and 15 km distance constraints. Modelled optimal school locations are examined in terms of their feasibility for school location planning.

The key findings are presented below:

- Non adherence to the 5 km distance norm has led to a situation of locational inefficiency that stems from close spacing of secondary schools and other schools in the education system of Baksa district. On average, secondary schools are located less than 2 km from each other and are less than 1 km from primary and upper primary schools. As a result, there is a proliferation of small sized schools with inadequate catchment areas to sustain demand. There is also a pattern of co-location of schools on separate sites that has inbuilt inefficiencies and suggests a process of rationalization.
- School utilization rates indicated that 70.5% of government secondary schools are operating at or below 50% capacity with corresponding low enrolments and low student-teacher ratios. It is estimated that there are presently 2,691 surplus seats available across the secondary system in Baksa district.
- GIS analysis of village level census data indicates that there are 713 geometrically correct village boundaries –a large number of small villages. Demographic data for villages indicates that the secondary school age population of Baksa over the next 5-10 years will decline in net terms. This no growth in demand situation has an immediate effect on demand for new schools.
- Projected demand by persons aged 14-15 (grades 9-10) is only expected to increase over the next 2 years so that the number of schools expected of size 160 is 75 across the district.
- GIS based network analysis procedures (location-allocation) were used to determine the optimum locations of these 75 new secondary schools and the optimum allocations of villages to these locations using the criterion of minimizing distance and the criterion of maximizing coverage with capacity constraints. A 5 km distance norm was used as was the secondary school size norm of 160 enrolments. The 75 optimum locations does not imply closure of existing schools – these are the result of a modelling exercise that could assist school planners in assessing the locational efficiency of existing schools.

- The 75 new secondary school locations are associated with an average distance travelled of 2.6 km and average size of catchment area of 32.9 sq. km. These catchment areas are sustained by relatively high population densities and population figures are above minimum threshold values.
- Additional GIS based analysis indicates that the 75 optimum locations, based on location-allocation modelling, correspond to existing locations of schools within a 1km, 2km and 3 km distance band. For example, it was found that 25 out of the 75 optimum locations have government secondary schools located with a 1 km distance from the respective optimum location – this increases to51 out of 75 optimum locations and 69 out of 75 optimum locations for 2 km and 3 km distances. The government secondary schools which are co-located with these optimum sites represent nearest best locations that could be the basis of maximizing efficiency using existing structures.
- The efficiency gains of the 75 optimal location solution to demand over the period 2016-2025 stems from lower numbers of schools and teacher requirements as compared to the existing situation. Analysis indicated that the total costs of providing 75 schools at a size of 160 were approximately $USD 7.91 million or equivalent to 520.3 million Rupees. Only 300 classrooms would be required and 375 teachers for the 75 schools compared to the present 1798 secondary teachers. Savings in teacher salaries were reduced from 539.4 million Rupees to 112.5 million Rupees on an annual basis.
- In relaxing distance norms and school size criteria, GIS was used to model the impact of schools of size 160, 340 and 520 with distance constraints of 5 km, 10 km and 15 km. By using these respective school sizes, it was estimated that there would be a need for 75, 35 and 23 new secondary schools respectively. Optimum locations and optimum allocations were determined for these scenarios using ArcGIS Network Analyst (locate-allocate) procedures and a range of accessibility characteristics are generated to allow comparison of the locational efficiency of various scenarios.
- As one increase school size and increases the distance constraints (5 km to 15 km) it was found that average distance travelled from a village (centroid) to an optimum school location increased from 2.8 km to 3.6 km for a school size of 160, from 2.7 km to 6.9 km for a school of size 340 and from 3.1 to 6.5 for a school size of 520. A doubling of school size, on average, leads to a doubling of the average distance travelled.
- Similarly, increases in school size and varying of distance constraints leads to enlargements in school catchments areas; these effectively double as school size doubles, but they also increase as the distance constraint increases. On average, the size of school catchments increases from 32.9 sq. km at a school size of 160, then to 62 sq. km for a school of size 340 and up to 79 sq. km for a school of size 520. These school catchments are sustained by high population densities and the optimum solutions provide a high level of coverage to the demand population – persons aged 14-15 over the next 5-10 years.
- Another outcome of the optimal location and allocation solutions is villages that are not allocated to optimum school locations due to location beyond the distance constraints used in the analysis. Non-allocated villages may require new school locations to meet unserved demand and/or introduction of a school transport subsidy scheme (or both) in order to facilitate student access to the new secondary school locations.
- While increases in catchment areas and average distance travelled may be viewed as negative outcomes of increasing school size and varying distance norms, these need to be traded-off against

efficiency gains. It was estimated that as school size increases from 160, to 340 and 520 students the corresponding decrease in total costs is from $USD7.9 million to $USD 5.6 million - a 28.2% reduction in total costs. Furthermore, the savings in teachers' salaries on an annual basis is from 534.9 million Rupees to 117.3 million Rupees – a reduction of 78% in salaries. It is these trade-off considerations that policy makers will need to come to grips with.

- There are also clear cost savings generated from the school size scenarios when compared to the situation with existing government secondary schools. The 75 potential schools of size 160, that would be fully resourced and equipped, and that would cost $USD 7.9 million, represents a very significant cost saving as compared to the estimated recurrent costs of the 147 existing secondary schools of $USD 13.4 million. In addition, it was estimated that it could cost in the order of $USD 3.5 million to remove the backlog of resource need for the current 147 government secondary school.
- Alternative school siting methods focused on rationalization of the existing distribution of secondary schools and the merger/closure of schools. Two approaches were assessed for a small area of Baksa district that contains low enrolment schools not generally related to the distribution of student demand for secondary education. These approaches entailed: rationalization of the network of low enrolment secondary schools, and; rationalization of all low enrolment government schools to form comprehensive schools from grades 1-10. The analyses indicated that it was very feasible to undertake both types of rationalization and that in most cases there was adequate capacity at an existing school to accommodate students from nearby schools that could be closed. The additional distances travelled as a result of this rationalization were minimal and did not exceed 800 metres of travel along the road network.
- GIS information was used to show how school resourcing issues could be visualized and diagnosed with the aim of identifying areas or schools with inequities and for proposing solutions. UDISE data was used to map school types, attributes of school enrolment size, school utilization rates, qualifications of teachers, facilities at schools and service areas around schools. The village census data was used to map population density and the distribution of persons aged 14-15. These maps indicate wide disparities in the quality of the secondary education system in Baksa district, especially the distribution of basic physical facilities for students across the secondary system. These GIS maps further highlight were resources are needed in order to optimize school resourcing for efficiency.
- The policy implications of the findings were discussed and these revolved around the need to support good quality GIS information, GIS technology and GIS training across the three levels at which MoE is present in order to enhance the analytical basis of school location planning. Policy makers also need to embrace the alternative school size and varying distance norm scenarios in order to markedly improve and optimize school siting and school resourcing into the future.

1. Introduction

The ToRs for this research indicate that various State governments use a combination of norms and standards to identify where to create additional secondary school capacity. “Of particular importance is the 5 kilometer distance norm that is applied to determine sites of new schools or the ones to be upgraded.”

It has been noted that the current approach does not take into account geographical constraints as well as population distribution thus leading to inefficient and often inequitable distribution of resources. These concerns demand a robust analysis of the current methodology using GIS approaches and use of the findings to suggest alternative school mapping methods.

1.1 Objectives of the Study

The study aims to demonstrate a GIS application to determine efficiency gains and losses of applying different criteria for new school establishment. The aim is to develop a list of criteria for establishing new schools under different settings, and to identify and demonstrate use of GIS in school planning and management. More specifically, the study involves combining a school mapping approach and GIS technology in Baksa district of Assam state for determining school locations for the unserved communities and their resourcing.

This would involve integrating school coordinates, GIS related overlays for roads, topography, elevation, demography etc. and linking GIS coordinates of schools to UDISE codes and census information. In addition, a manual is to be developed for undertaking GIS based modeling for planning new school locations; the manual also serves to demonstrate how GIS applications and GIS information can be used for planning decisions.

The study aims to answer the following questions:

- How many secondary schools (along with their locations) will be needed if the plans are developed using school planning norms and what will be their respective school size over next 5-10 years?
- What are the implications of relaxing distance norms and using school size criteria to determine school location?
- What are the efficiency and effectiveness trade-offs associated with different methods of school siting?
- How can GIS information be used to optimise school resourcing for ensuring maximum efficiency?

Location-allocation analysis is used to determine the optimal locations of schools using different distance norms and optimality criteria. A total of three school size scenarios are modelled; schools of size 160, 340 and 520. For each scenario, two optimality criterion are examined: minimizing average distance of the secondary school age population in villages to the nearest school facility and, to maximize the secondary school age population covered with capacity constraints. For each criterion four distance norms are assessed: no distance constraint, 5 km, 10 km and 15 km distance constraints. Modelled optimal school locations are examined in terms of their feasibility for school location planning.

This research paper, which constitutes the first output of the research, addresses the above questions using data from Baksa district of Assam state. The report is structured as follows. Section 2 provides a brief overview of some of the key data sources and data quality issues faced in undertaking this research that would be of importance for local school planners. Section 3 provides a summary of the key characteristics of the 147 government secondary schools in Baksa and of the primary school system. A further summary is provided of the village based census data that is the basis for enrolment projections. Section 4 examines the first question and explains the enrolment projections generated for the period 2016-2025.

Subsequently, GIS analysis is used to identify optimal locations of secondary schools and their allocations to meet projected demand over the period 2016-2025. Section 5 examines the second question and provides GIS based evidence of the impact on school travel of varying school size and distance norms. Section 6 provides a summary of the effectiveness and efficiency trade-offs associated with different methods of school siting. Section 7 provides additional examples of how GIS can be used to understand the distribution of education resources across Baksa district. Section 8 discusses the key policy implications of the main findings of the study. The final section, Section 9, concludes with some key lessons for school policy makers and school location planners.

2. A note on Data Sources and Data Quality

Several GIS data layers of Baksa district were made available for assessment of quality and suitability for use in GIS analysis. These included: Roads, Water features, Settlements represented as points and as areas, Rail and a GIS layer of Village boundaries. Specific comments were previously disseminated on the suitability of all these layers and these are not reported here. However, note should be made of comments on the road layer and the village boundary layers.

A key problem with the road layer was the aggregated nature of the roads that had been digitised – all were main roads – and the digitised length of a line to represent distances between places. This meant that most villages were not connected to the road network and, more importantly, that most schools were not connected either. To overcome these problems, a more detailed and disaggregated road network was required. The methodology used for this process and the outcome is discussed in Section 4.

The village boundary layer(s) provided by the census office in Assam state indicated a total of 736 villages in Baksa. Two separate village files were provided but both contained digitisation errors (duplicate boundaries and duplicate villages) that were corrected, with the result that the number of villages was reduced to 713. Several village boundaries were outside the boundary of the district. Each village has a unique code but 174 villages had missing codes and 5 villages had a missing village name and code.

Data for all schools in Baksa and Assam state came from UDISE for 2013-2014. The UDISE data for schools contains significant errors that appear to be associated with data entry and it is clear from analysis of this data that final validation has yet to be completed.

In addition, an Excel file of the Anganwadi census that had been recently completed and validated by the TCA team was also made available. This was a full census of every village in Baksa and contains relevant school age population data (by yearly age) plus data on total households. A key task during the mission was to match the village names on the Anganwadi census file with the codes and names on the village boundary file. This proved problematic given absence of standardization in spelling of village names and absence of corresponding codes for villages. Use was made of the 2011 Census data dictionary to determine codes for villages in the GIS layer and to match as many of these with names and codes in the Anganwadi file. However, it was not possible to match 154 villages from the Anganwadi census file to a corresponding village code and, therefore, to a corresponding village in the GIS layer. Attempts were made by the TCA team to contact the local census office for assistance but it was not possible to obtain the required information.

A procedure was subsequently established that involved use of the 2011 GIS digital village census boundaries for Baksa and availability of the corresponding online census data for these villages. The 2011 census GIS layer which contains 699 villages was overlaid with that provided by Assam state. This did not assist with identifying missing codes but the 2011 layer provided information on total population. GIS was used to overlay both layers and extract a corresponding total population figure for villages with missing information based on the percent of land area that a village occupies of their corresponding 2011 census village boundary (in some cases it could occupy several 2011 census villages). The extracted total population figure was then used to estimate the number of persons in single years (ages 6 to 17) of school age based on their corresponding percent of the estimated total population from the Anganwadi census file. Estimated total population was based on multiplying the total number of households in a village by the average number of persons per household (4.9) as reported in the 2011 census.

A total of 929,182 persons were estimated to be living in the Anganwadi villages that were part of the TCA census. This compares with a total population of 950,075 from 699 villages recorded in the 2011 census data. This difference could be due to outmigration but, more likely, is due to differences in the number of villages and their boundaries. However, one of the many benefits of the Anganwadi census file is that it contains the number of persons in each village of secondary school age (age group 14-15) that are generally found in grades 9 and 10 of secondary schools. This data was used as the basis for assessing demand for government secondary schools and the number of government secondary schools that will be needed over the next 5-10 years.

In discussing issues of GIS data quality, the point that should be noted by school planners and policy makers is that good quality data and data at the right scale is essential for robust analysis of the education system. School planning and management in Baksa and, indeed, across Assam state should be working to constantly improve the quality of GIS and education data being used for analysis of the education system.

3. Characteristics of Schools and Villages in Baksa

The study area, Baksa district, is located in the north-western part of Assam state and the northern boundary of the district is part of the international boundary between India and Bhutan. It is enclosed by north-south flowing river systems of the Pathumari, in the eastern part, the Pagladiya in the central-eastern part and the Beki in the western part, and by an international boundary with Bhutan in the north. These major river systems, together with some minor rivers, form geographic barriers for movement of people, including school children travelling to and from school.

In 2015, the district's population was 929,182 based from the Anganwadi census file. Although the Anganwadi census file does not indicate a distinction between which villages are rural or urban, it would be safe to assume that the majority of the population would be classed as rural. Using the GIS layer for villages, which was linked to the aggregated Anganwadi file, and to GIS calculations of an area attribute for each village, it is estimated that gross population density is 531 persons per square kilometre, with little variation across the villages. There are a few pockets of very high density located in the northeast and western parts of the district (see Figure 21).

3.1 Schools

There were 1479 primary schools, 376 higher primary and 36 higher primary schools with secondary sections where the management was the Ministry of Education (hereafter referred to as government schools) based on the UDISE data for 2013-2014. The higher primary schools also have lower primary sections, so a total of 1891 schools were educating at the primary level (grades 1-8). At the secondary level, there were107 secondary only government schools, 4 secondary schools with higher secondary sections and 36 upper primary schools with secondary or higher sections – a total of 147 schools were educating at the secondary level (Figure 1) in 2013-2014 where the management was the Ministry of Education. Only 16 government schools across Baksa district educate students at the higher secondary level.

The distribution of all government schools is shown in Figure1. There is a broad distribution of primary schools across Baksa district, as with secondary schools. Higher concentrations of schools are found in the central and eastern parts of the district. Several schools are located outside of the extent of village boundaries for Baksa, but appear to be located within the boundary of Baksa district (as of 2014). It is important to note that, based on a closer (zoomed in) view of the locations of schools (Figure 2), that many primary, upper primary and secondary schools are located in very close proximity of each other, usually within a one kilometer distance. Many secondary only schools are located next to an upper primary school. One interpretation of the pattern in Figure 2 is that the 5 kilometre distance norm does not appear to have been applied in the historical pattern of locating secondary schools.

A more detailed GIS based assessment of the spacing of government secondary schools in Baksa, using the 5 kilometre norm, indicates that the overwhelming majority of secondary schools are located well within the 5 kilometre norm (Figure 3). While the 5 kilometre buffer represents an aerial distance (does not consider actual road distance), it is a solid representation of the cumulative results of secondary school location siting decisions in the district. The central and eastern parts of Baksa district stand out as having locations of secondary schools very closely spaced to each other. Further analysis indicated that the majority of government secondary schools are within a 2 kilometre buffer (map not shown). There are three areas shown in Figure 3 where the buffers do not overlap, an indication of unserved areas for secondary education. However, upon closer inspection of these areas it is apparent that they contain upper primary with secondary and upper primary with secondary and higher secondary schools.

GIS was also used to calculate the average aerial distances separating the various categories of schools relative to government secondary schools. Table 1 highlights the results of these calculations. In relation to the feeder schools of a secondary school – upper primary schools (grades 6-8) – these are, on average, located only 260 metres from a secondary school (a point noted from Figure 2). However, for primary schools with upper primary sections, the distances are, on average, much further from a secondary school (12.1 km). There are only 9 primary with upper primary schools in Baksa and these are located a long distance from the nearest government secondary school. Other feeder schools within the 5 kilometre radius of a secondary school are the upper primary with secondary schools.

Figure 4 indicates that there is wide variation in size of secondary schools with a large number of low enrolment schools (less than 100 enrolled) located in the central part of Baksa district. Many of these locations correspond with villages that have low numbers of persons aged 14-15. In general, there appears to be little evidence of the association between the locations of government secondary schools and the distribution of demand for these schools in the district. Further, the map highlights that there are some very large government secondary schools in Baksa, generally spread across the district (the largest having an enrolment of 703 students). However, many of the high enrolment secondary schools are not found in those villages having high numbers of persons aged 14-15 in the population.

A detailed breakdown of the size of secondary schools and those with secondary components to them highlights that larger schools are not a characteristic of the education system in Baksa district. On the contrary, it is the smaller schools that characterize the government secondary education system.

Figure 1: Distribution of Government Schools in Baksa District

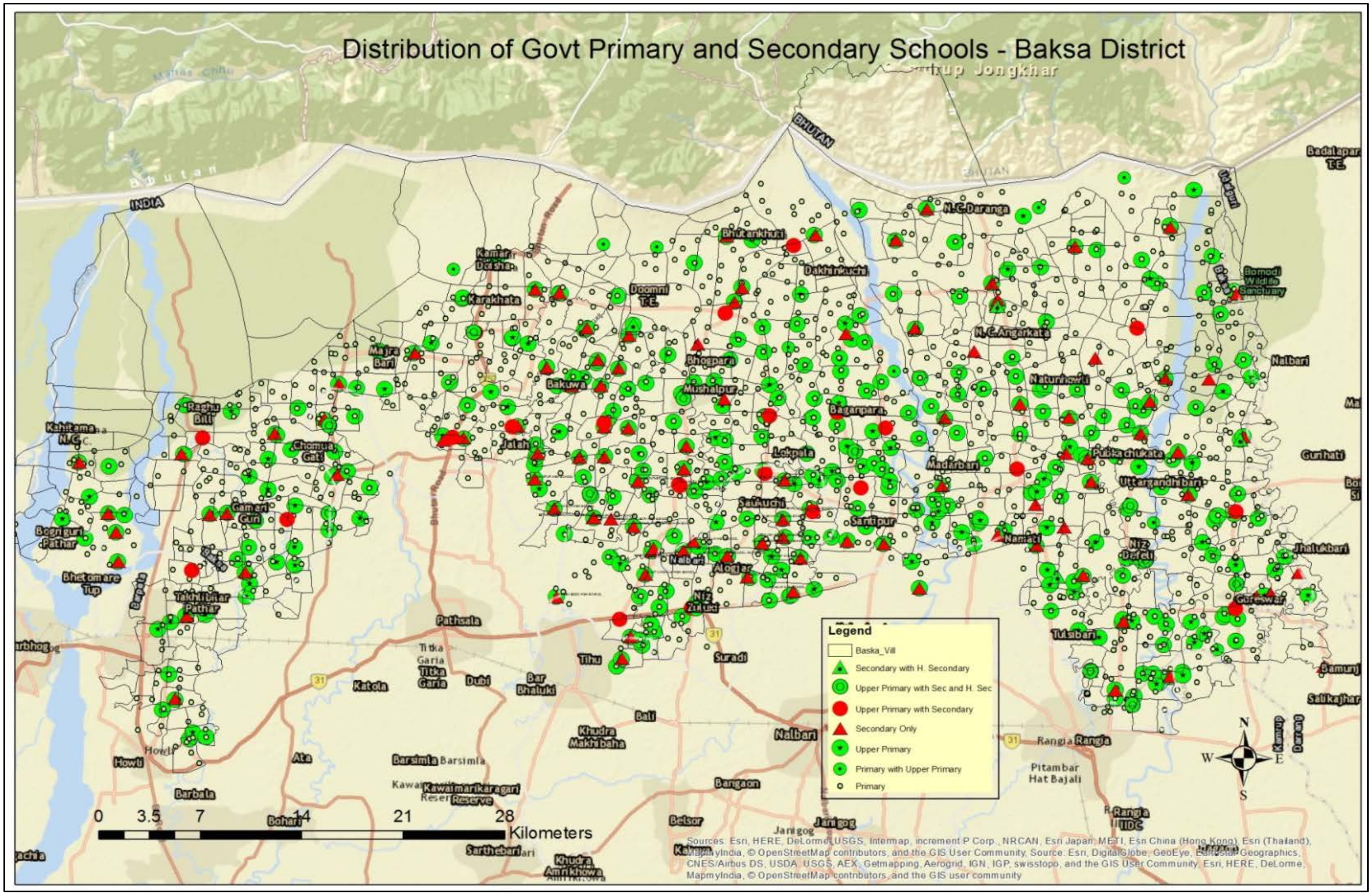


Figure 2: Distribution of Government Schools in Baksa District – A Detailed View

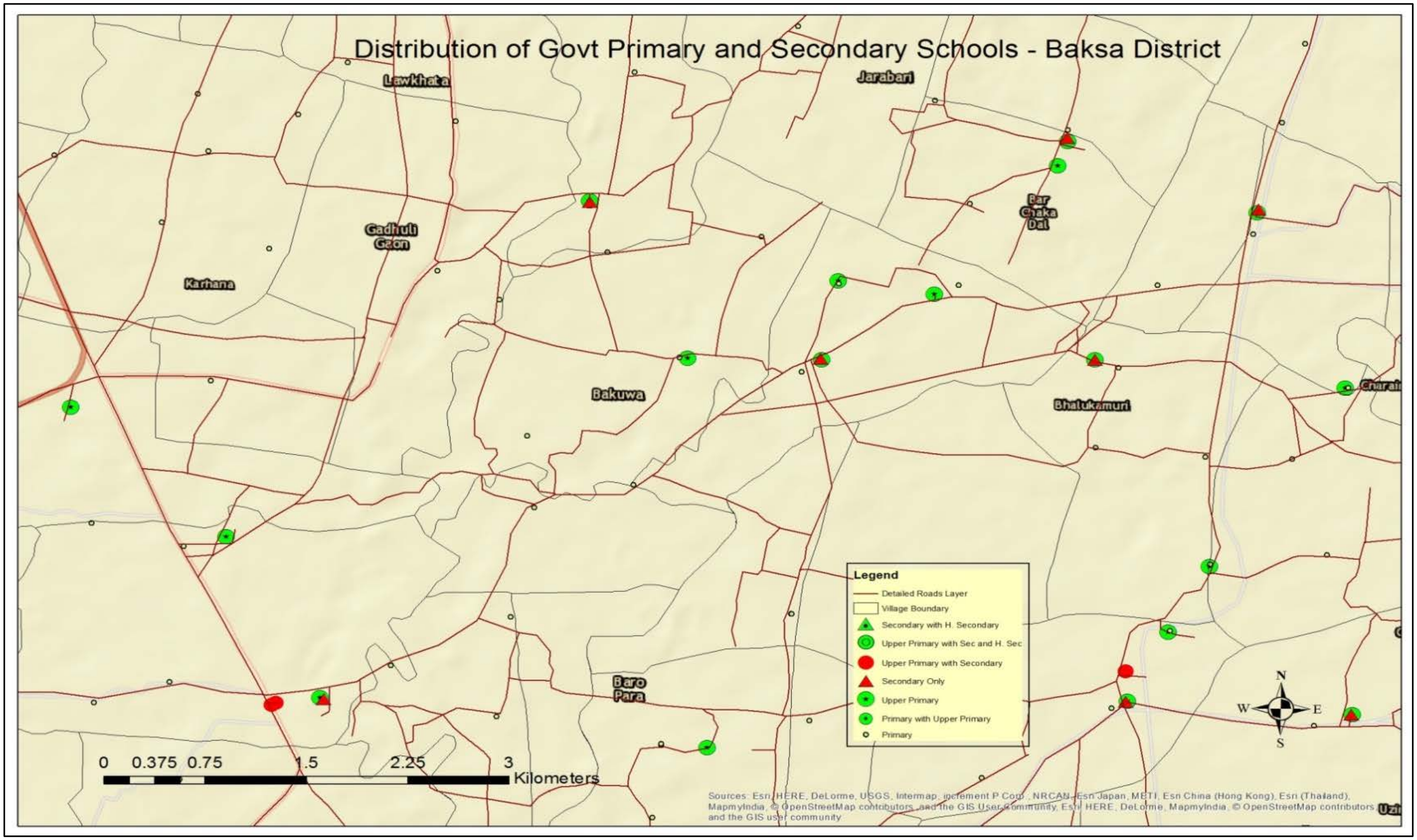


Figure 3: Five Kilometer Buffers around Government Secondary Schools

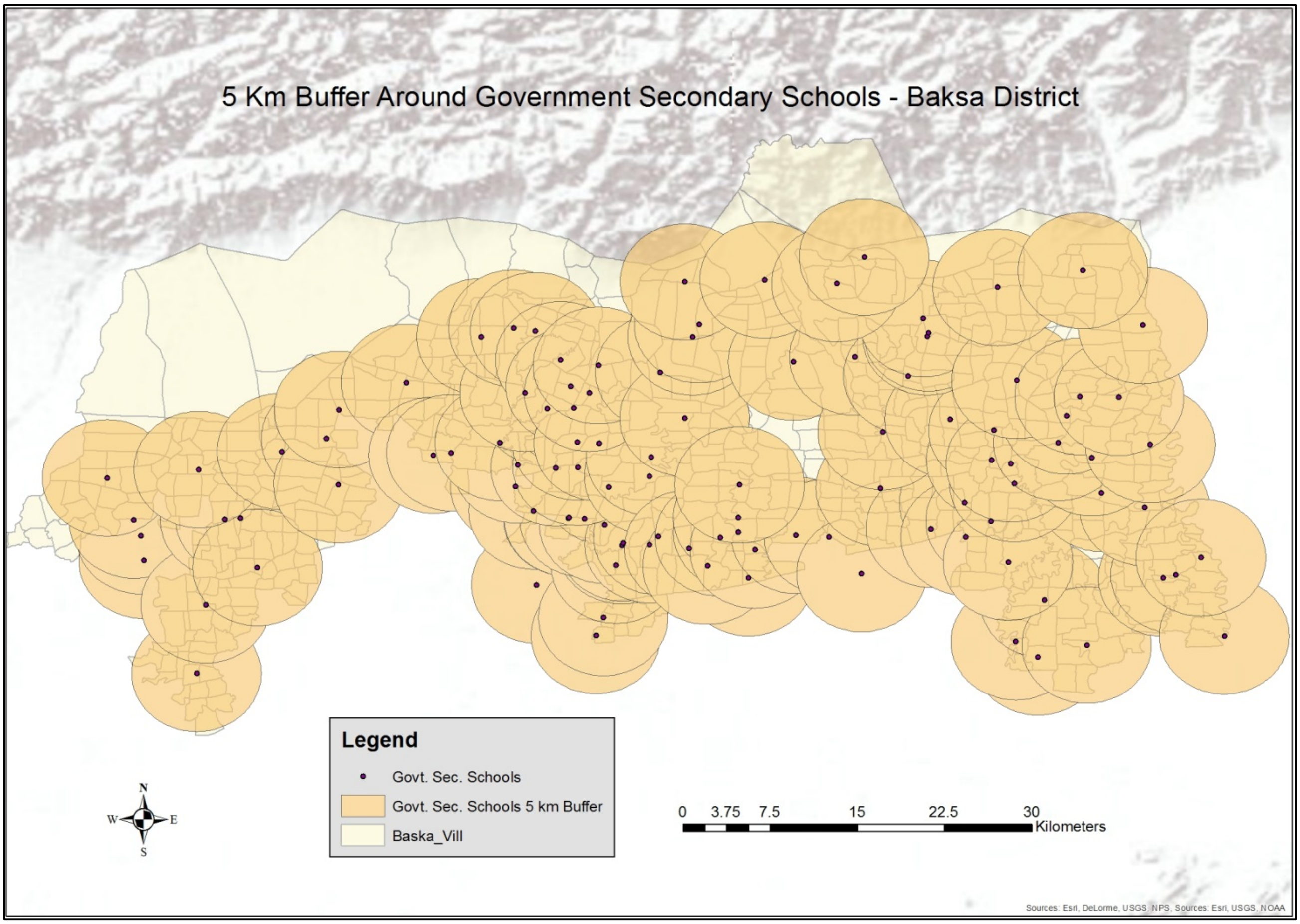


Table 1: Distances between Schools – Baksa District

Distances Between Govt. Secondary Schools and other school categories:	Average Distance (Km)	Minimum Distance (Km)	Maximum Distance (Km)
Primary	0.28	0.0	1.1
Upper Primary	0.26	0.0	5.1
Primary with Upper Primary	12.1	3.1	36.1
Upper Primary with Secondary	4.8	0.025	10.9
Upper Primary with Secondary and Higher Secondary	7.1	0.10	20.1
Secondary with Higher Secondary	12.9	0.19	41.4

Figure 4: Enrolment and Population Distribution

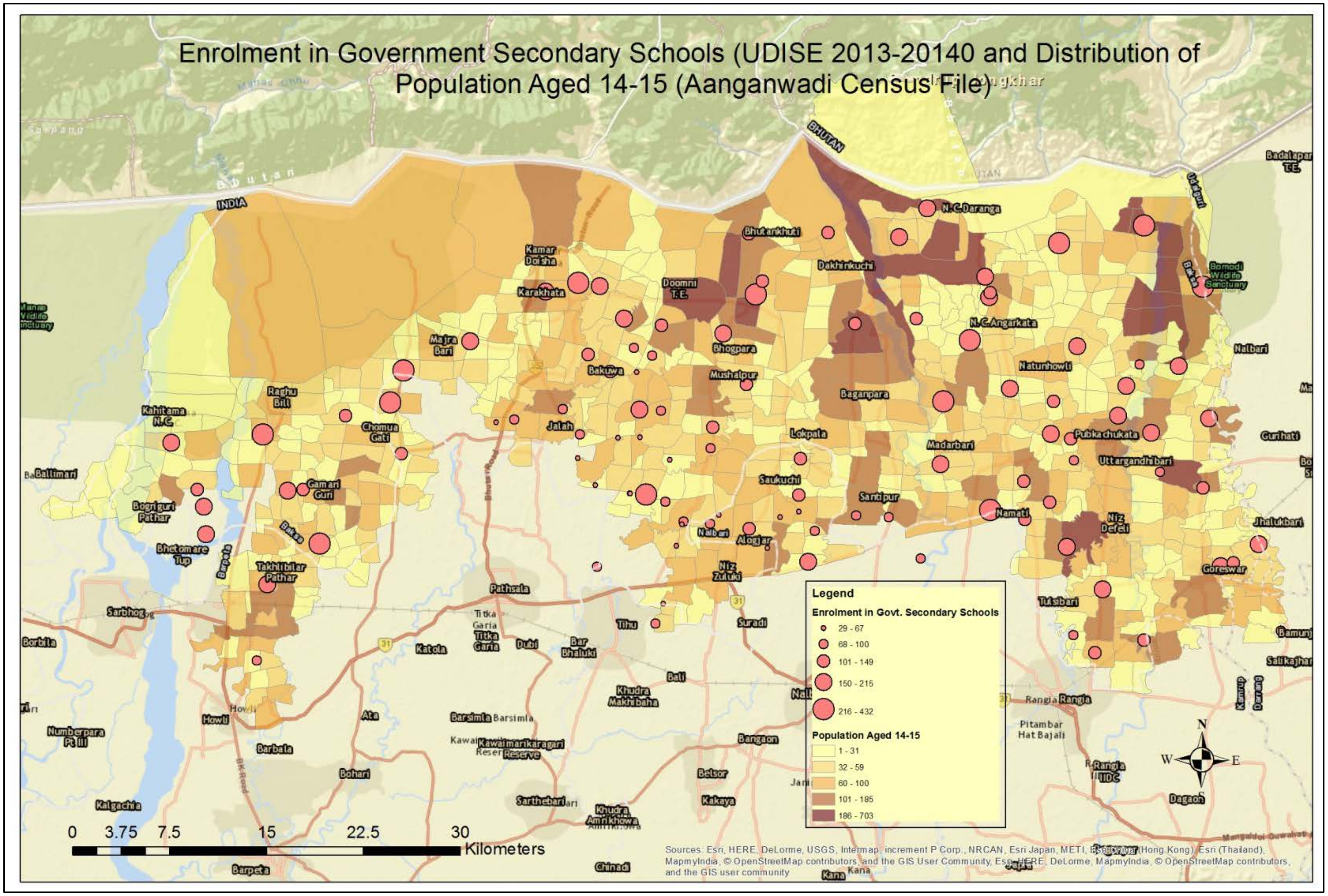


Table 2 indicates that 38 out of 107 secondary only schools (35.5%) have fewer than 100 enrolled students according to UDISE 2013-2014. Twenty percent of schools (22 out of 107) have enrolments less than 75 students. It is interesting to note that upper primary (with secondary component) schools generally have enrolments over 100 students and a significant number of these exceed 250 in size.

The large number of relatively smaller sized secondary schools is likely to affect the level of efficiency of space utilisation at a school. One way to understand space utilisation is to examine the utilisation of a school in comparison to its capacity (ratio of enrolment to capacity). Those schools where enrolment approaches, or is equal to, capacity are fully utilised (at 100% of their capacity). Using the UDISE 2013-2104 data for secondary enrolment, secondary classrooms and average students per classroom, school utilisation rates have been calculated for the types of secondary schools in Baksa district. A maximum size of 40 students per classroom has been assumed for these calculations.

Table 2: Size of Government Secondary Schools in Baksa District

Size Category Of School (Enrolment) UDISE 2013-2014	School Description				Total
	Secondary Only	Secondary with Higher Secondary	Upper Primary with Secondary	Upper Primary with Secondary and Higher Secondary	
0-25	0	0	1	0	
26-50	4	0	1	0	5
51-75	18	0	0	0	18
76-100	16	0	2	0	18
101-125	16	1	1	0	18
125-150	11	0	3	0	14
151-175	11	0	2	2	15
176-200	11	0	4	0	15
201-225	8	1	1	2	12
226-250	2	0	2	0	4
Above 250	10	2	7	8	27
Total	107	4	24	12	147

Table 3 highlights school utilisation rates for the 147 government secondary schools. Nineteen government secondary schools (12.3%) are operating above their capacity (taken to be 100%), and 13 (3.9%) of those schools could be considered to be overcrowded. Only 6 schools are operating at or close to their enrolment capacity (91%-100%). Of significance is that 70.5% of government secondary schools are operating at or below 50% capacity. (42% of government secondary schools are operating at or below 30% capacity). The low level of utilisation that characterises government secondary schools would also be reflected in a smaller size of school and lower student-teacher ratios.

GIS was used to map the distribution of school utilization rates (Figure 5). It is evident from this map that the highest concentration of low utilization government secondary schools is found in the central parts of

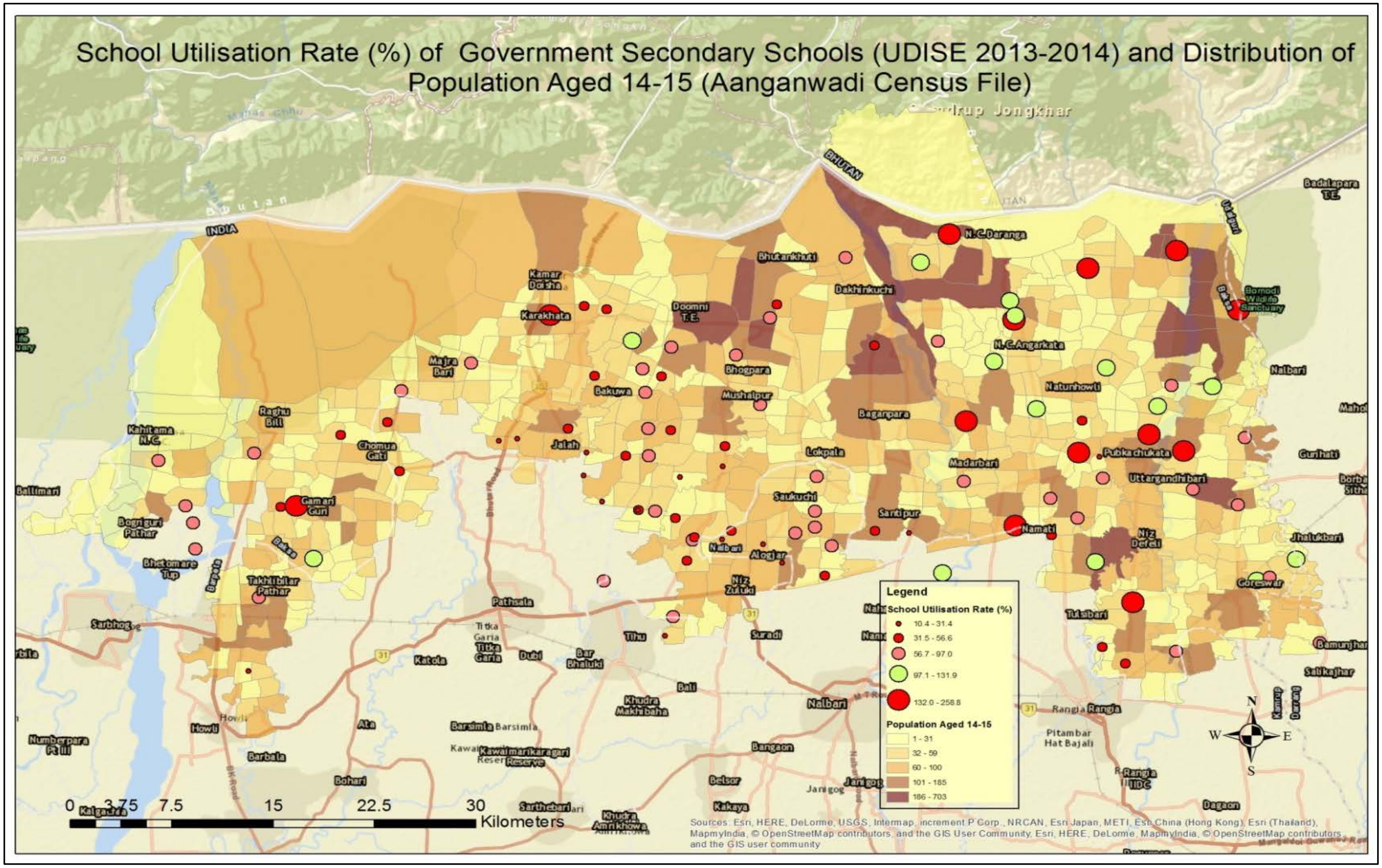
Baksa district (smaller red circles) although low utilization schools are also found in the western and eastern parts. It is also evident form this map that, generally, many of the low utilization secondary schools are found in areas where there are relatively small numbers of persons aged 14-15 in the population of villages. This suggests that many schools are generally located where catchment areas do not have sufficient demand for students and where potential enrolment growth in the catchment zone is limited, possibly due to changing demographic characteristics.

The analysis of enrolment versus capacity for government secondary schools using the UDISE data indicates that there are presently 2,691 surplus seats available across the system (capacity exceeds enrolment). This is a large number of available seats and would be equivalent to having 17 schools (assuming a minimum of 160 students per school) in the system not being utilised for education purposes. Surplus seats occur across the district but are very prominent in the central part of Baksa. The presence of a large number of surplus seats has policy implications as it suggests the need for extensive rationalisation of resources in the form of mergers and/or closures. It also implies that no new schools should be constructed in the future until future demand is first allocated to schools with excess capacity.

Table 3: School Utilisation Rates – Government Secondary Schools

School Utilisation Rate	Number of Schools	Percent
0%-10%	11	7.4
11%-20%	26	17.6
21%-30%	25	17.0
31%-40%	24	16.3
41%-50%	18	12.2
51%-60%	10	6.8
61%-70%	1	0.6
71%-80%	7	4.7
81%-90%	5	3.4
91%-100%	1	0.6
101%-120%	6	4.0
121% - 180%	11	7.4
More than 180%	2	1.3
Total	147	100.0

Figure 5: School Utilization Rates for Government Secondary Schools



3.2 Villages and their population

As mentioned in section 2, there are 713 geometrically correct village boundaries that have been used in the GIS analysis. The primary data for each village is the Anganwadi census data. This data file contains a census count of every person for single year ages from less than 1 year of age up to 20 years of age. In addition, it records the number of households per village. This value has been used to estimate total population for ach village assuming 4.9 persons per household. Table 4 highlights the single year ages and their corresponding proportion of the estimated total population of villages in the census.

Table 4 indicates that the secondary school age population of Baksa villages in 2015, those aged 14-15 years of age, only constitute 3.9% of the total population. Of significance is that there is not expected to be any increases in the secondary school age population over the next 5-10 years. Table 4 highlights that there will be absolutely and relatively fewer persons who will fall into the 14-15 year ages between 2016 and 2025 than what there are in 2015. There is no evidence of growth in the school age population aged between 6 and 15 years of age. This may be due to low growth rates in the population but to other factors as well. This has implications for school planning and the expected number of schools over the next 5 to 10 years – a subject of the next section.

4. Research question 1: Secondary School Requirements and their Locations over the next 5-10 years

Section 4 describes in detail the procedures developed and applied to determine the number of new schools required for Baksa district up to 2025.

4.1 Secondary school requirements

The starting point for assessing the number of new schools and their optimum locations is the Anganwadi census data file. As mentioned previously, this file contains information on current numbers of persons aged 14-15 (in 2015) and future numbers of persons who will be in the 14-15 year age group between 2016 and 2025. The key assumptions in the process of working out the future school age population are as follows:

- A 100% gross enrolment rate - where it is assumed that all students will be in a government secondary school
- The numbers of students in government secondary schools according to UDISE 2013-2014 are assumed as stable in 2014-2015 (similar numbers).
- The 147 government secondary schools are assumed as placed or fixed locations. They do not figure in the analysis of new school locations as the interest is in new locations which minimise distance according to school planning criteria.

The steps described below detail the procedures developed and adopted to estimate the relevant secondary school age population. The discussion is based on the Excel file named **'Projection of Baksa School Needs 2016-2025_v3'** which accompanies this report.

Step 1: Secondary school age students 2016-2025

According to UDISE 2013-2014, a total of 24,123 students were enrolled across the 147 government secondary schools. This represents a gross enrolment rate of 66.4% using the total of 36,331 persons aged 14-15 in 2015 across Baksa villages. It is assumed this total of 24,123 students is enrolled in 2015.

Table 4: Single Year Age Characteristics of Baksa Villages

Age characteristics of Baksa villages	Total	Percent of Total Population (%)
Less than 1	13,817	1.48
One	15,548	1.67
Two	16,756	1.80
Three	17,816	1.91
Four	17,604	1.89
Five	18,347	1.97
Six	17,544	1.88
Seven	17,762	1.91
Eight	17,362	1.86
Nine	16,682	1.79
Ten	17,654	1.89
Primary	87,004	9.36
Eleven	17,191	1.85
Twelve	17,858	1.92
Thirteen	17,836	1.91
Upper Primary	52,885	5.69
Fourteen	18,245	1.96
Fifteen	18,086	1.94
Secondary	36,331	3.90
Sixteen	17,405	1.87
Seventeen	16,077	1.73
Higher Secondary	33,482	3.60
Eighteen	16,941	1.82
Nineteen	17,683	1.90
Twenty	17,504	1.88
Estimated Total Population	929,182	
Total Households	189,629	

Step 1 involves identifying the numbers of persons who will be aged 14-15 for each year over the period 2016-2025. This information is taken directly from the Anganwadi census file and is also shown in Table 4. For example, in 2016, the number of persons aged 14-15 are those presently aged 14 (18,285) and those now aged 13 (17,836) – a total of 36,081. In 2017, the number of persons aged 14-15 are those presently aged 12 (17,858) and 13 years of age (17,836) – a total of 35,694 persons. Following this logic, those persons aged 14-15 in 2020 are those presently aged 9-10 years of age (total of 34,336 persons) and those persons aged 14-15 in 2025 are those presently aged 4-5 years of age (a total of 35,951 persons).

As mentioned previously in section 3, it can be seen that the number of persons aged 14-15 declines between 2016 and 2025.

Step 2: Annual increment of persons aged 14-15

The annual increment of persons aged 14-15 in over the period 2016-2025 is calculated in order to see the number of new persons aged 14-15 added each year. (The base year of 2015 is critical for this estimation). As mentioned above, the base number of students used is 24,123 (this represents a gross enrolment rate of 66.9%). In 2016, the number of persons aged 14-15 will be 36,081. If a 100% enrolment rate is assumed then a total of 11,958 additional students will require places in new schools in 2016.

Annual increments of persons aged 14-15 between 2017 and 2025 actually declines over this period. In fact, there is a net decrease of 494 persons aged 14-15 over this period despite some increases in the years 2022 and 2024. This implies that the number of schools to be provided for those new persons in the years 2016 will be more than adequate to meet demand that would be declining between 2017 and 2025.

Step 3: Size of secondary schools and expected numbers of secondary schools

Using the criteria of a minimum school size of 160 for a secondary school, the Excel worksheet **'Expected Schools'** indicates that, based on a demand of 11,958 persons aged 14-15 in 2016, there would be a requirement for 75 new schools in 2016. This number would be adequate in terms of capacity to meet the expected number of persons aged 14-15 between 2017 and 2025.

The Excel worksheet also indicates the number of government secondary schools that would be required if school size was set at 340 students and 520 students – 35 and 23 new schools respectively. These are the basis of analysis for the second research question that involves relaxing distance norms and using school size criteria to determine the location of schools.

It is of the highest importance to stress that the modelling exercise of determining the optimum locations of 75, 35 and 23 new schools respectively should not be interpreted as meaning that all government secondary schools be closed and that 75, 35 or 23 new secondary schools be built in their place.

4.2 Optimum location-allocation of new government secondary schools 2016-2025

The method used to determine the optimal locations of new government secondary schools was location-allocation modelling. The mathematical formulation of the location-allocation models used in this research is described in Appendix 1 (Technical Appendix). These same location-allocation models, which find optimal locations with respect to criteria such as minimizing distance, maximizing the population covered and maximizing the population covered subject to capacity constraints of the optimal locations, have been applied to optimal school location problems by Moller-Jensen (1998), Mattsson (1986) and, more recently, by Ndiaye et.al (2012). A more detailed discussion of location-allocation heuristics can be found in Revelle and Swain (1970).

As mentioned in Section1, location-allocation modelling is used to determine the optimal locations of schools for three school size scenarios; schools of size 160, 340 and 520. For each scenario, two optimality criterion are examined: minimizing average distance of the secondary school age population in villages to the nearest school facility and maximizing the secondary school age population covered with capacity constraints. For each criterion four distance norms are assessed: no distance constraint – fixed school size only; a 5 km distance constraint where school size is fixed and there is a maximum distance constraint of 5 km; a 10 km distance constraint where school size is fixed and there is a maximum distance constraint of 10 km, and; a 15 km distance constraint where school size is fixed and there is a maximum distance constraint of 15 km.

In the case of the first school size scenario of 160 students, the two optimality criterion are interpreted to mean the following: (1) to minimise the average distance travelled of the population aged 14-15 found in villages to the nearest optimal school location subject to four distance norms: no distance constraint, and; maximum distance constraints of 5 km, 10 km and 15 km, and (2) to maximise the population aged 14-15 found in villages subject to the capacity constraint that an optimal school location has a maximum capacity of 160 students (4 classrooms at 40 students each), and subject to four distance norms: no distance constraint, and; maximum distance constraints of 5 km, 10 km and 15 km.

The focus of the first school size scenario of 160 students is on the first two distance constraints; no distance constraint – fixed school size only, and; a 5 km distance constraint where school size is fixed and there is a maximum distance constraint of 5 km. The use of a maximum service distance of 5 km was based on the school planning norm of providing the rural population with a secondary school within 5km. Similarly, the norm of a secondary school having a minimum size of 160 students was the basis for a capacity of 160 in each optimum secondary school location. However, use of the 160 school capacity constraint implies that some optimum locations will have less than the capacity of 160 students based on what villages are allocated to the optimum location.

Furthermore, while minimizing average distance and maximizing population coverage are closely related to the utilisation of optimal school locations, the impact of physical geographic barriers would also affect accessibility and be an important consideration in determining optimal school locations. As mentioned in Section 3, the district of Baksa is enclosed by the north-south flowing river systems of the Pathumari, in the eastern part, the Pagladiya in the central-eastern part and for Beki in the western part which, together with some minor rivers, form geographic barriers of movement of school children travelling to and from school. The GIS layer of rivers for Baksa district (a polygon layer) is used as the basis of the physical barrier constraints. This effectively means that optimal school locations and allocations of villages to these optimal facilities will, for the most part, not involve crossing a river. The only exception to this physical constraint is if a village is located close to the road network that crosses a river (via a bridge) or an optimal school location is close to the road network that crosses the river.

Optimal secondary school locations generated by the two optimality criterion are compared based on measures such as average distance travelled from villages to the set of optimal locations in the total system, average number of villages within the catchment area of the optimal school locations, average size of population aged 14-15 in the total catchment area, average number of villages in the catchment area within 5 km of optimal school locations and, the total weighted cost of each solution. The latter may be interpreted as the total person-kilometres travelled in each optimal solution – a measure of the total travel cost for the population aged 14-15 in reaching the optimal set of secondary schools in the system.

The computations of accessibility measures and optimal locations were implemented by the Network Analyst extension using the Locate-Allocate procedure in ArcGIS Desktop 10.3.1. The Network Analyst extension is required for the operation of the Locate-Allocate procedures.

The location algorithm works by identifying an optimum set of new secondary school locations from a pool of candidate locations, using the objective functions identified above. The allocate algorithm works by assigning population aged 14-15 located in villages to the nearest optimal location such that the greatest amount of demand can be served without exceeding the capacity of the optimal school locations. ArcGIS is used to map the optimal locations and allocations using the two optimality criterion discussed above. The value of using GIS for this analysis, with ArcGIS in this case, lies not only in the availability and functionality of the Network Analyst extension, but the ability to utilise and manipulate other geographic layers required for the analyses.

4.2.1 Pre-processing of GIS data layers: road network and village data

The Network Analyst extension in ArcGIS requires the following GIS layers and datasets to be used with the Locate-Allocate procedure:

- A topologically correct (i.e. connected) road network dataset made up of nodes and lines (edges) with length or time attributes as measures of impedance. The nodes of the network are the basis for determining the optimal locations of new facilities (secondary schools)
- A GIS layer of demand points; village boundaries GIS layer (polygon) must be designated as points (centroids) with their corresponding population attributes that will act as the demand to be satisfied, and
- A GIS layer of polygon barriers; in this case the polygon layer of rivers for Baksa district.

The following general steps were used in ArcGIS to pre-process the GIS data layers or to generate the new GIS layers (e.g. roads):

Step 1: convert the village boundary layer to a point layer where each point represents the centroid of the village (or the geographic centre of a village) and the centroid stores all attributes associated with a village. The feature to point tool in ArcGIS Toolbox was used to generate a layer of village centroids.

Step 2: generate a detailed road network for Baksa district. The following procedures were followed:

- Download of high resolution satellite imagery (available from ESRI) to cover Baksa district and act as a background layer. The high resolution nature of the imagery allows sealed and unsealed roads to be identified as networks connecting most villages and towns

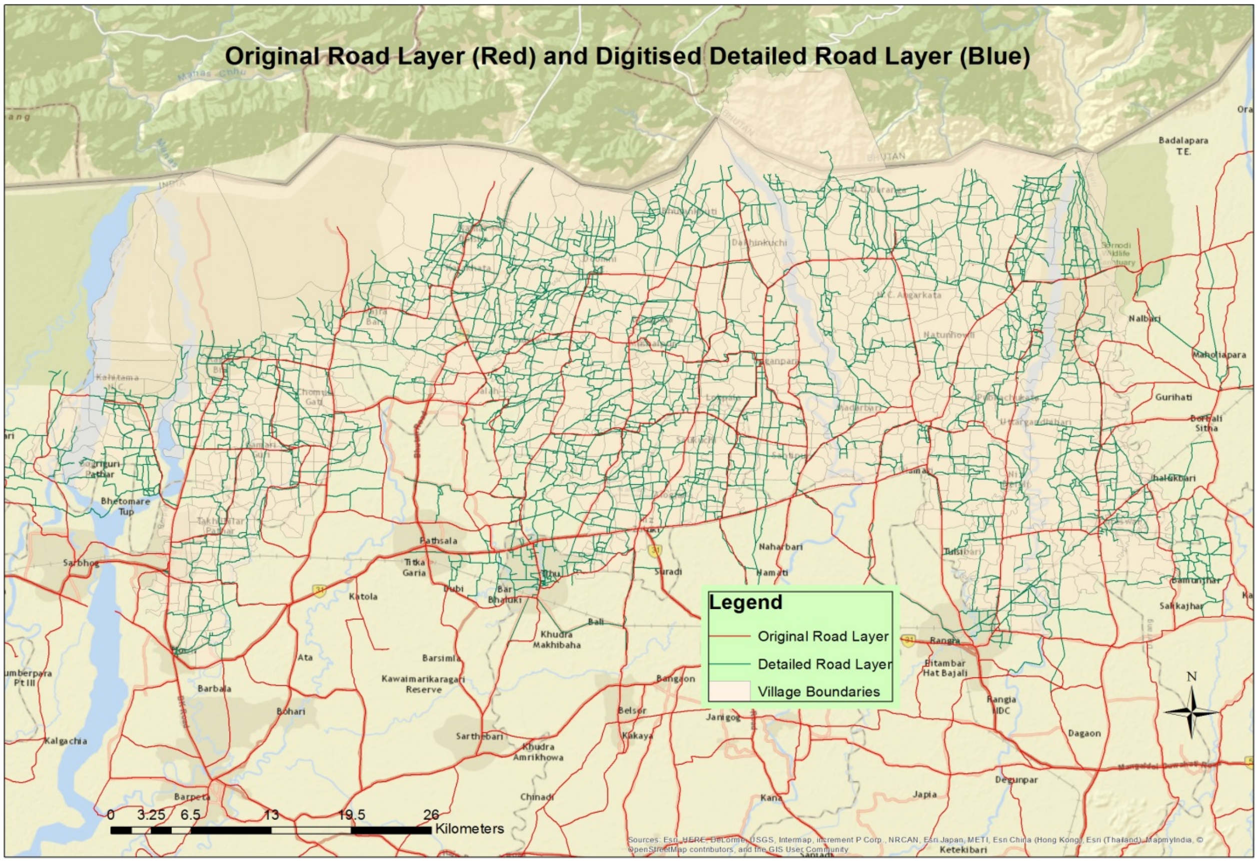
- Download of the World Streetmap layer (available from ESRI) to cover Baksa district and act as another background layer. This layer is not of adequate resolution for developing more disaggregated road networks but, instead, provides the names and locations of major roads
- Digitisation of a more disaggregated road network connecting most villages and towns.

Figure 6 shows the original road network obtained from the Assam state geographic centre (in brown colour), and the more disaggregated road network layer developed for this research (in blue colour). The World Street Map layer is in the background.

- The GIS layer of the disaggregated roads is first checked for its geometrical accuracy. Any geometric errors such as lines not joining junctions or over-shooting junctions are corrected.
- The corrected GIS road layer is then converted to a topologically correct ArcGIS road network dataset for use by Network Analyst. A key attribute of the road network dataset is the length in metres of each link (line or edge) connecting two nodes (junctions). A key feature of the network road dataset is establishment of topological properties between every line (edge) and node (junction).
- The road network dataset is tested for correctness by using the Service Area procedure in Network Analyst to generate a 1000, 2000, 3000, 4000 and 5000 metre service area around each village centroid.
- The Network Analyst Service Area procedure, as with the Locate-Allocate procedure, links the village centroids to their respective closest node on the road network so that proper distance calculations can be made.

It should be noted that the more detailed road network digitised for this study represents one level of disaggregation – one that is much more detailed than what was provided. An even more detailed network could be digitised with availability of additional time. It is estimated that to digitise every section of road and path connecting every village, town and government secondary school in Baksa district would require at least 4-5 months of labour. The scale and level of disaggregation at which the more detailed road network has been developed is considered more than adequate for the purposes of this research exercise.

Figure 6: Original Roads Layer and Digitised Detailed Roads Layer



4.2.2 Location-allocation analysis

There are several key assumptions that define the location-allocation analysis as undertaken for this research:

- Only nodes on the network can be candidates for optimum locations of new schools.
- Only villages that have more than zero students as demand can be considered as points of demand.

Using the above assumptions, the Locate-Allocate procedure in ArcGIS (Network Analyst) determines an optimum set of new school locations. The number of new schools required is pre-determined from the analysis conducted in section 4. In this process, existing schools are not considered when determining new optimum locations.

It should be stressed that modelled optimum school locations, which are nodes on the road network, do not necessarily represent the actual locations – the feasible locations - of any potential new schools. There are many factors that govern what are feasible locations of new schools, land availability being a primary one. It is up to MoE to determine the actual site of a new school within those villages (village boundaries) for which the Locate-Allocate procedure has determined optimum locations. However, this approach depends on whether a new school is deemed necessary, as the focus may be on using existing schools and excess capacity in those schools (see Section 6.3). The value of the location-allocation modelling is that it allows school planners to compare modelled outcomes with their own proposed or existing school locations.

The Locate-Allocate procedure also records those villages with potential demand that are allocated to each respective new optimum location based on minimum travel distance and capacity of the new location. In this research paper, the two accessibility criteria mentioned above are the basis for interpretation of the locational efficiency of the optimum location-allocation solutions.

4.3 Results: Map output

The outputs of the location-allocation procedure lend themselves to visualisation in ArcGIS, but also to tabular output. Table 5 summarizes the accessibility characteristics for the criteria of minimizing average distance within 5 km of an optimum location and maximizing coverage with capacity constraints within 5 km of an optimum location. While the average distance travelled is almost identical for both solutions, as are the maximum distances travelled (given the distance constraint used), the minimizing average distance solution offers a higher level of locational efficiency as compared with the criterion of maximizing coverage with capacity constraints. The percent of the demand that is reached or covered with the minimizing average distance criterion (94.1%) is much higher than the 81.8% reached by the criterion of maximizing coverage with capacity constraints.

Table 5: System-Wide Accessibility Characteristics: 75 Optimal Secondary School Locations

Accessibility Characteristics	Minimizing Average Distance: School Size Fixed and Maximum Distance of 5 km[a]	Maximizing Coverage With Capacity Constraints: Fixed School Size Fixed and Maximum Distance of 5 km[a]
Average distance travelled	2.8	2.6
Maximum distance travelled	4.9	4.9
Number of villages covered within 5 km	637	557
Percent of persons aged 14-15 covered	94.1 (11,255)[b]	81.8 (9,782)[b]
Average number of villages per catchment area within 5 km	8.5	7.4
Average number of persons aged 14-15 per catchment area	150	130
Average population of villages per catchment area within 5 km	11,672	10,154
Total weighted cost: person-kilometres travelled	30,364	23,274

[a] Physical barrier constraints are also included in the objective function.
[b] Numbers in brackets represent the total number of persons aged 14-15.

This is also evident in higher values for number of villages covered within 5 km, average population of villages within 5 km, average number of villages per catchment area and average number of persons 14-15 in the villages per catchment area. Due to the fact that more demand is covered by the minimizing average distance solution, there is a trade-off in terms of a higher number of person-kilometres travelled, when compared with the maximum coverage solution. The person-kilometres travelled (or total weighted cost in ArcGIS) is a measure of the total travel cost for the population aged 14-15 (demand in this case) in reaching the optimal set of secondary schools in the system. Values for this characteristic are lower for the maximizing coverage solution due to the consideration of capacity constraints. This means that, on average, capacity at the optimum facilities is filled from villages located at shorter distances to the facility as compared with the minimizing average distance solution.

Figures 7 and 8 show the geographic distribution of the 75 optimal school locations for each criterion and the villages allocated to each optimum location (catchment area within 5 km). In the minimizing average distance solution, the persons aged 14-15 in villages allocated to an optimum solution is not constrained by a capacity (size =160) at the optimum school location. This means that numbers allocated to an optimum location in this criterion may be under or above the value of 160.

While the number of optimal locations is the same in both solutions, their distribution is somewhat different; however, it should be noted that the geographic spread of optimum locations in the eastern, central and western parts of the district is almost identical for both solutions. In the maximum coverage solution, the combined effect of the 5 km distance constraint and a maximum capacity at an optimum location of 160 means that many more villages lie outside of these constraints (shown in blue) as compared with the minimizing average distance solution. In the latter solution, most of the villages not allocated to an optimum location (also shown in blue) are found in the east, central, south and western parts of the district.

Those villages shown as allocated to an optimum location are allocated so that they are within 5 km of an optimum location. Those shown as not allocated are either beyond the 5 km distance criteria or not reachable from the optimum location given physical barrier constraints. The cluster of villages in the western part of Baksa located around the western edge of the Beki river fall into this category as does the cluster of villages in the far eastern and north-eastern part of the district around the Pathumari river system. These particular villages would need to be examined by the school location planners of the district with a view to the particular circumstances generating non-allocation. In some cases an additional school(s) may be required in close proximity of these clusters of villages.

It should be noted that 2 of the 75 optimum locations fall just outside the boundaries of the villages for Baksa district (Figures 7 and 8). The first location is in the lower western part of Baksa and is located within the eastern boundary of the city of Howli, less than 1 km to the boundaries of the villages of Gahe Khanda and Khatal Para. The other optimum location is located at Dhamdhama just south of the villages of Santipur and Ghorbitor. In both these cases, the school planners could move the optimum locations to be within the village boundaries while still keeping the 5 km distance norm.

Figure 9 provides a more detailed view of an optimum location and the villages allocated to this location as part of the modelling exercise. The optimum location is a node on the road network (shown in light grey colour) and is located within the boundary of the village of Jara Bari. A total of 9 villages have been allocated to this optimum location; Saru Chakadal, Pani Mudi, Jala Gaon, Bata Bari, Duwa Gaon, Arkora, Bakuwa, Dangari Gaon and Jara Bari. The 9 villages are represented by their centroid points (in blue) and by a straight line connecting the centroid to the optimum location. (The straight line connection is for display only to highlight what villages are allocated to an optimum location). However, the 9 villages are allocated to the optimum location in such a way that they are within 5 km of the optimum location.

Figure 7: Optimal Locations of 75 Secondary Schools with Minimizing Distance Criterion

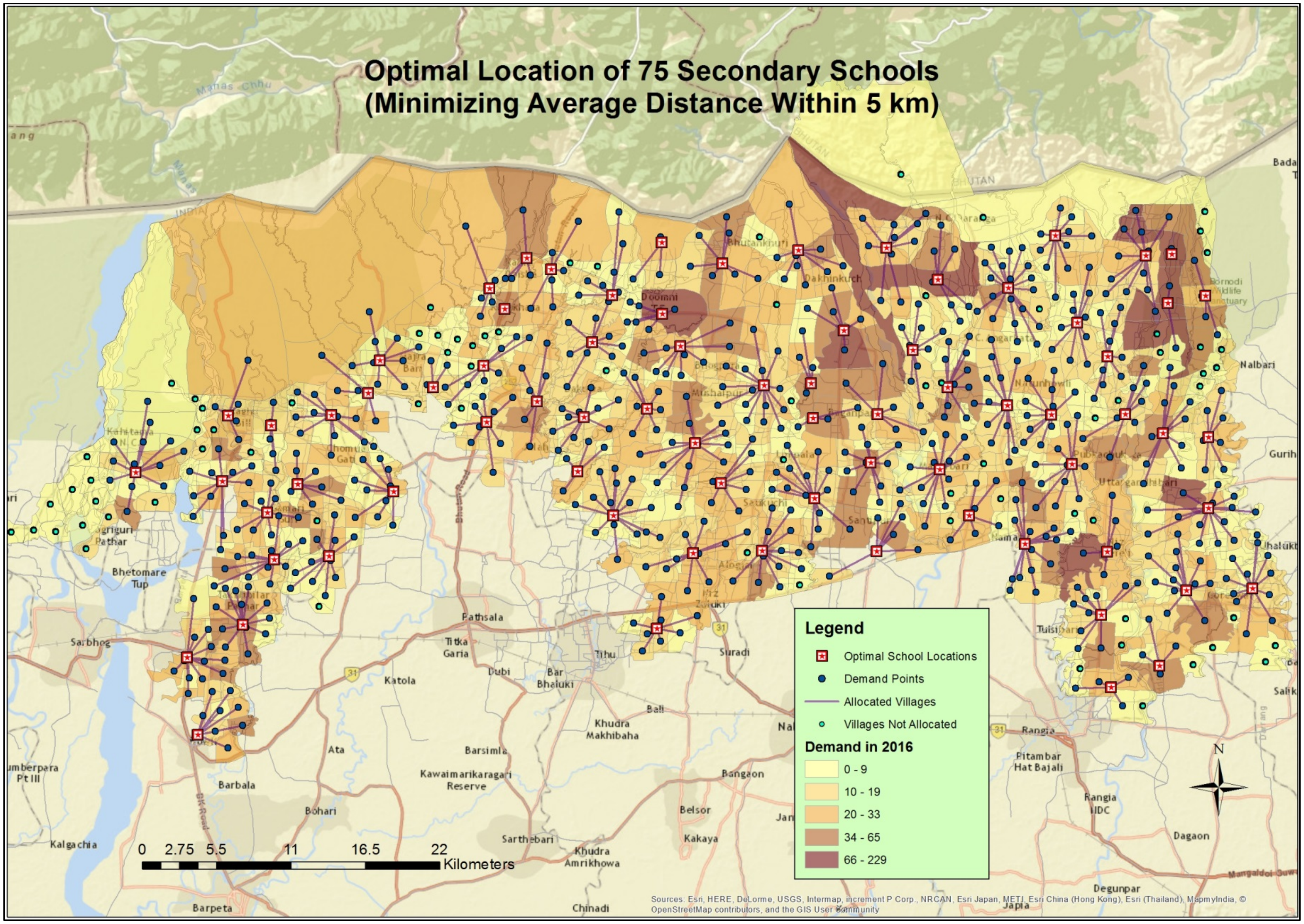


Figure 8: Optimal Locations of 75 Secondary Schools with Maximizing Coverage with Minimum Constraints Criterion

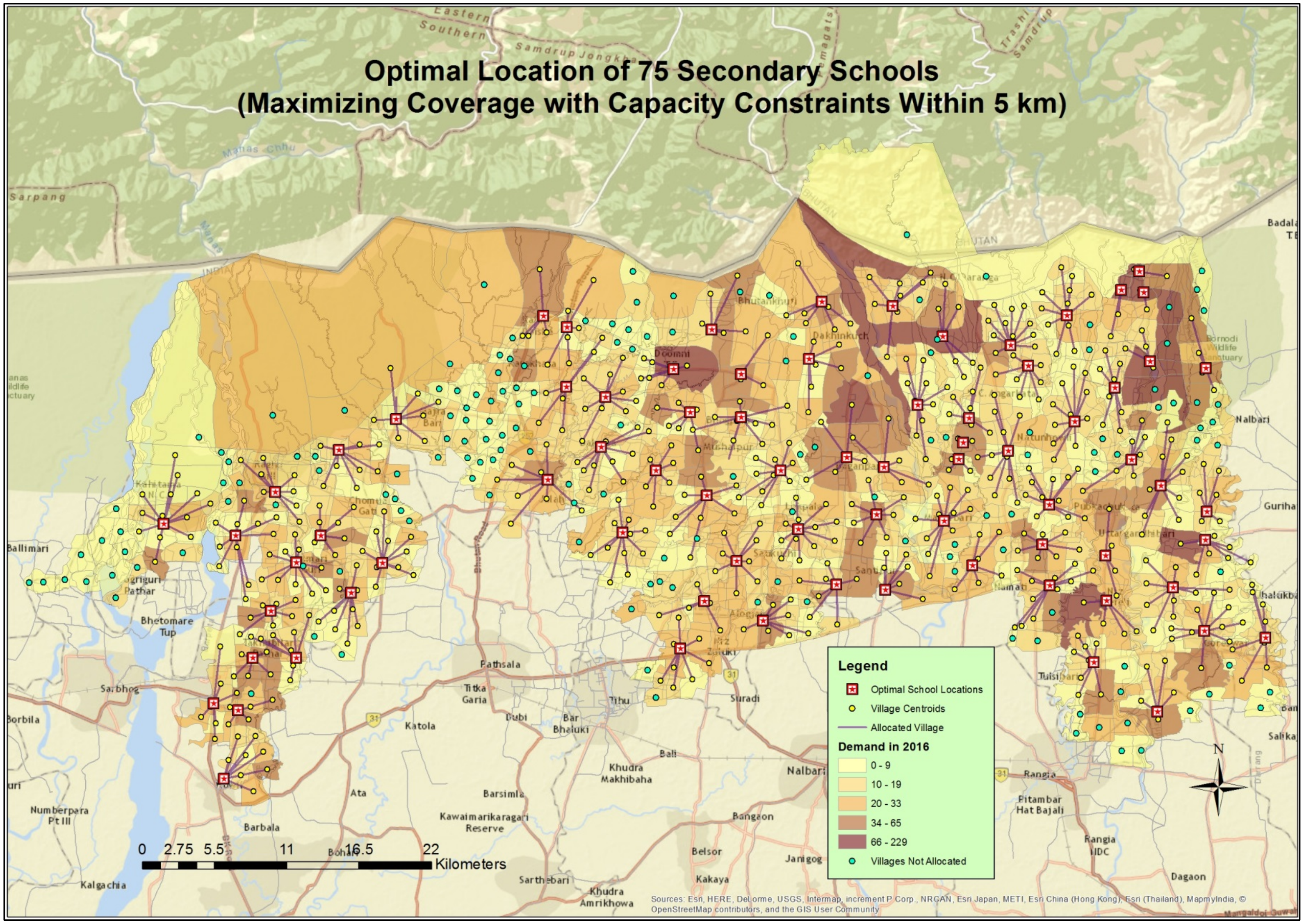
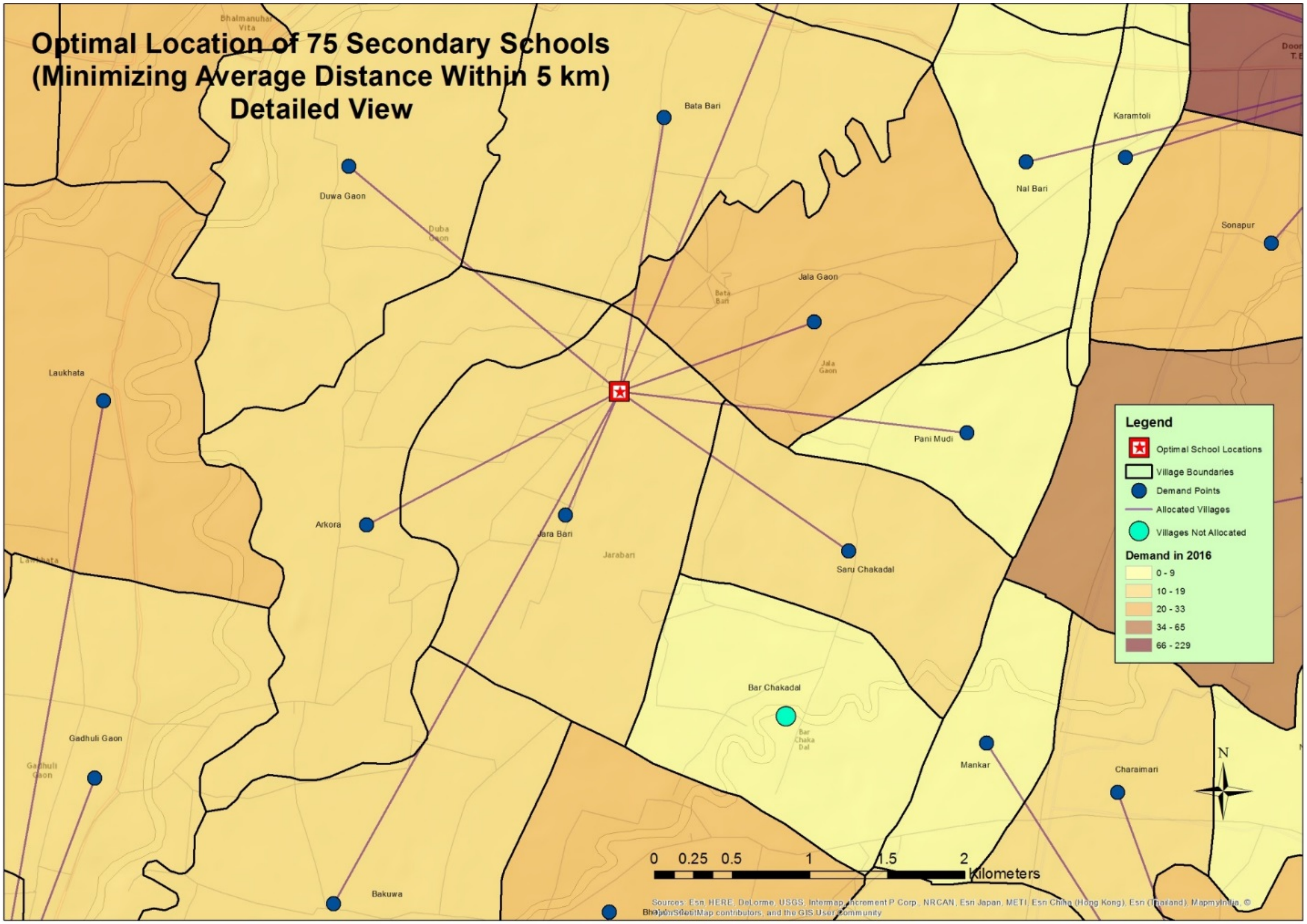


Figure 9: Optimal Locations of 75 Secondary Schools – Detailed View



The blue point represents the centroid of a village not allocated to any optimum location – this village is called Bar Chakadal. Upon closer inspection it is apparent that non-allocation to the optimum location in Jara Bari stems from the fact that the centroid point lies on the southern side of the physical barrier of the Deka Dong River. Even though the centroid of Bar Chakadal is located approximately 4 km by road network from the optimum location, the use of a physical barrier constraint in the minimizing average distance solution results in a non-allocation. Bar Chakadal is too far (beyond 5 km) from any other surrounding optimum locations to be allocated to these sites. In this situation, the school planners would allocate Bar Chakadal to the optimum location in Jara Bari. It is recommended this process of checking each non-allocated village be carried out to determine the specific circumstances of non-allocation.

Figure 9 also indicates that the catchment areas around optimum locations are not circular, nor hexagonal, in shape. Their geographic shape varies according to the configuration of village boundaries, in this case, as the centroid represents the village boundary. As can be seen from Figures 6 and 7, the shapes of the catchment areas vary depending on how many villages are allocated to each respective optimum location, but each village is allocated to its closest (within 5 km) optimum location.

GIS can also be used to generate indicators of the relative size of catchment areas, even for a specific catchment area such as that around Jara Bari. Indicators of the size of catchment areas provide school location planners with a sense of the existing and longer term demand for a secondary school.

Table 6 provides an example of these indicators for the village catchment area around the optimum location in the village of Jara Bari. The size of the catchment area is 29.5 sq. km and the average population density is 415.9 persons per sq. km. Average values and minimum and maximum values across the 75 catchments associated with the 75 optimum locations indicate variation across the system. Some of the village boundaries that form part of a catchment have extremely small areas. The minimum value of 0.19 sq. km is for the village of Narayangaon in the south-eastern part of Baksa district. However, from Table 5, the average number of villages in a catchment area is 8.5. When this value is multiplied by the average size of a catchment area, the average size of a catchment is 28.8 sq. km. This size of catchment area, and the relatively high population density figures in catchment areas, signify that there is more than adequate threshold population density and total population to support the opening of a new school, should it be required.

Table 6: Select Indicators for Catchment Area of Optimum Location in Village Of Jara Bari and Across the System

Indicator	Catchment Area Around Jara Bari[a]	Across System of Catchment Areas[a] (n=75)		
		Average	Min	Max
Average population density in catchment area (persons p.s.k)	415.9	559.3	3.2	6,007
Total population in catchment area	11,928	12,088	9.0	17,971
Total persons aged 14-15 in 2016 in catchment area	128	155	1.0	228
Size of catchment (sq. km)	29.5	32.9	0.19	132.0

[a] Based on minimizing average distance criterion.

One of the key questions to emerge from the results of the location-allocation modelling of the 75 optimum school locations is what other government secondary schools are within close proximity of these optimum facilities? For school location planners, the practicality of close proximity of existing schools to modelled locations lies in the potential to maximize the efficiency of existing structures. Those optimum locations in close proximity of existing secondary schools could be viewed as the nearest best locations. This approach is very similar to that discussed in Section 6 – maximizing efficiency of existing schools and rationalization of low efficiency schools.

To highlight the importance of the above question, an analysis is undertaken using GIS (near distance tool) to determine how many of the 75 optimum locations have government secondary schools within 1km, 2km and 3 km, where two optimality criterion have been used with the 5 km maximum distance constraint. In addition, the characteristics of average distance and maximum distance between an optimum location and government secondary schools is calculated in the GIS to show just how close these schools are to an optimum facility together with size characteristics of these schools. Table 7 presents the results of this analysis.

Table 7: Proximity of Existing Secondary Schools to 75 Optimum Locations

Indicator	Minimizing Average Distance: School Size Fixed - 5 km Maximum Distance			Maximizing Coverage with Capacity Constraints: School Size Fixed - 5 km Maximum Distance		
	1 km	2 km	3km	1 km	2 km	3 km
Number of optimum locations with secondary schools within distance band	25	51	69	31	55	64
Number of government secondary schools within distance band	29	73	119	31	68	111
Average distance (km)	0.49	1.15	1.64	0.37	0.96	1.53
Maximum distance (km)	0.99	1.99	2.94	0.91	1.99	2.99
Minimum size of government secondary schools within distance band	53	29	8	51	41	41
Maximum size of government secondary schools within distance band	432	530	530	409	530	530
Average size of government secondary schools within distance band	176	175	166	192	191	170
Student-teacher ratio	12.8	13.4	12.9	14.0	13.5	12.5

Table 7 indicates that of the 75 optimum locations, 25 (33.3%) have government secondary schools located within a 1 km distance of the optimum facility (minimizing average distance solution within 5 km). These 25 optimum locations have a total of 29 government secondary schools that are within 1 km., and the average distance of these 29 schools to the 25 optimum locations is only 490 metres. The number of schools increases to 73 and 119 for the 2 km and 3km distances respectively.

The number of optimum locations with government secondary schools located within 2 km and 3 km distance of the optimum facility increases accordingly as does the average distance – from 51 to 69 optimum locations respectively. This indicates that 69 out of 75 (92%) optimum locations have secondary schools within 3 km of their respective locations, with average distances at 1.34 km. similar trends are observed for the number of optimum locations with government secondary schools for the maximum coverage with capacity constraints solution.

These findings suggest that most of the 29 schools around the 25 optimum locations, or the 73 schools around the 51 optimum locations and the 119 schools around the 69 optimum locations can be considered as nearest best locations in terms of any reorganization of the secondary school system and maximization of efficiency using existing structures. Given the relatively short average distances, these nearest best locations could be characterized as having locational efficiency in terms of student travel to these locations.

Figure 10 provides an example of the location of 51 optimum locations (out of 75) that have secondary schools within 2 km of their respective locations (for the minimizing average distance solution only). In addition, the Figure indicates the location of those government secondary schools within 2 km of these optimum facilities. These 51 locations, and the schools within a 2 km distance, are fairly evenly spread throughout Baksa.

The above GIS exercise could be repeated for the 35 and 23 optimum school location problems where school sizes are 340 and 520 respectively. This has not been completed in Section 5 as the example above highlights that even the latter optimum locations would be associated with government secondary schools within the 1-3km distance bands, and would also be considered as nearest best locations for maximizing efficiency using existing structures.

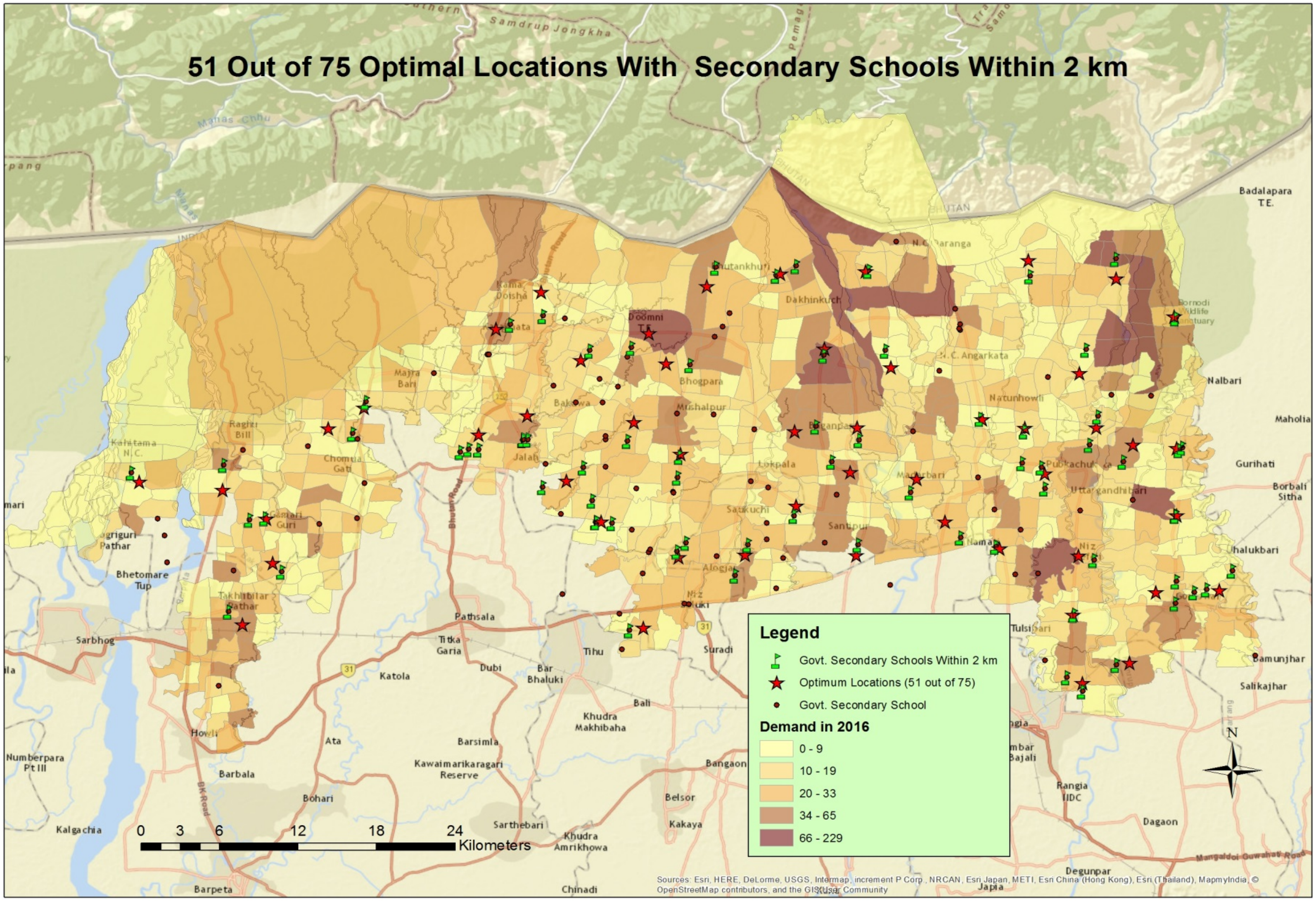
4.4 Efficiency gains of 75 optimum locations

The basic question here is what are the efficiency gains for the education system of having 75 new secondary schools in optimum locations that are within 5 km of a village? The Excel file that accompanies this report **'Projection of Baksa School Needs 2016-2025_v3'** provides estimates of total costs and of resource requirements for a minimum two section lower secondary school (grades 9-10). These basic requirements were provided by the TCA team. Based on the units of room needed per school of size 160, fixed costs and costs of staffing and operations per school, the grand total costs in Lakhs, Rupees and $USD for providing 75 schools at a size of 160 were calculated. Total costs amount to 520,285,714 Rupees which is equivalent to approximately $USD 7.91 million.

In terms of resource needs, the Excel file (Costings worksheet) indicates that 75 schools of size 160 would require 300 classrooms, 375 teachers and other classroom resources. This compares with the current provision in the 147 secondary schools of 507 classrooms and 1798 secondary teachers. The total of 375 secondary teachers represents a 79% reduction in the numbers of teachers required to provide lower grade secondary education in the system. There is also a corresponding savings in teacher salaries; for example, the 1798 secondary teachers presently in the system are estimated to cost 534.9 million Rupees on an annual basis, whereas 375 teachers would only require 112.5 million Rupees in salaries on an annual basis – a reduction of 79% in salaries.

Similar efficiency gains are discussed for other models of school size in section 6.

Figure 10: Optimal Locations with Secondary Government Schools within a 2 Km Distance Band



5. Research Question 2: Implications of Relaxing Distance Norms and Using School Size Criteria to Determine School Location

Section 5 describes results of procedures developed and applied to assess the impacts of alternative school size models and alternative distance norms.

There are two approaches that can be used to answer the above question. First, a school size can be fixed and then GIS is used to determine the optimum locations of the number of secondary schools required, the average distances travelled, size of catchment areas and other accessibility characteristics using the two criteria of minimizing distance and maximizing coverage. Second, the catchment area can be fixed using a formula that determines the catchment area size based on a maximum travel distance and other information such as enrolment rate and proportion of the secondary school age population to the total population. The latter method of calculating catchment areas was initially articulated by World Bank (1978) and has been used extensively in School Mapping exercises around the world. Following this, GIS would be used to determine optimum locations within catchment areas using the same two criteria of minimizing average distance and maximizing coverage.

In the second approach, values for population density and threshold total population are generated for a catchment area in square kilometres. This is based on factors of enrolment rate, proportion of the total population and maximum distance mentioned above. In the case of Baksa district, the catchment areas were calculated assuming a 5 km distance from home to school. The resulting size of circular catchment area (78.5 sq. km) would require a density of 52.2 persons per sq. km and a threshold population of 4,102 for a new secondary school to be planned (assuming an enrolment rate of 100%). Using GIS, it was found that only 18 villages are identified as having a population density below 52.2 persons per sq. km: these are mainly found in the more remote north-eastern and north-western parts of the district where there are national parks and forest reserves; several isolated villages are located on the flood plain of the Beki River in western Baksa, and; several are very small area villages with low population (See Figure 21). The overwhelming majority of villages in Baksa far exceed the minimum density requirements and this approach was, therefore, not pursued.

In the first approach, three school size models are tested using the following variations in distance norms: no distance constraint – fixed school size only; a 5 km distance constraint where school size is fixed and there is a maximum distance constraint of 5 km; a 10 km distance constraint where school size is fixed and there is a maximum distance constraint of 10 km, and; a 15 km distance constraint where school size is fixed and there is a maximum distance constraint of 15 km. The choice of school size models follows from the school size of 160 used for analysis in Section 4. TCA provided a file of resources and costs for various school size models ranging from a size of 160 up to a school of 1000 students. For the analysis conducted in this research, the minimum school size selected is 160, intermediate size is 340 and a larger size of 520 students was selected.

The GIS methodology used to assess the implications of varying school size and relaxing distance norms is similar to that used for the analyses in Section 4. The key steps are outlined below:

Step 1: school size criteria and number of schools required

Based on the expected demand of persons aged 14-15 in 2016 (see Excel file), the use of these school size models (160, 340 and 520) would require 75, 35 and 23 schools respectively.

Step 2: optimum locations for three school size models

GIS is used to generate optimum locations for each school size model and the four distance norms using the criterion of minimizing average distance and maximizing coverage with capacity constraints.

Step 3: generate accessibility characteristics and map output

Tables of accessibility characteristics are presented for each school size model with variation in distance norms. Maps are generated of the optimum location solutions for the minimizing distance criterion and the criterion of maximum coverage with capacity constraints.

5.1 Results

5.1.1 School size model of 160 students

Tables 8 and 9 present results of using GIS to determine the optimum locations of 75 new secondary schools using the two criteria identified above, and the variations in distance norms: no distance, 5 km, 10 km and 15 km. A 10 km distance norm or constraint was selected as it is generally considered to be the maximum distance that secondary school students should travel from home to school. Values for the 5 km distance norm are similar to those presented in Table 5 and are presented again in Tables 8 and 9 for comparison purposes.

It is of interest to note, that for both optimization criteria, the use of a no distance constraint in the solutions generates very long maximum distances from a village centroid to the set of optimum locations (23.8 km and 32.7 km respectively). One result is that average distances show a small increase from 2.8 to 3.6 km but taper off at a distance constraint of 15 km. Maximum distances travelled also increase in line with the distance constraint. These long maximum distances would be considered totally unacceptable given that most secondary students would be walking to school. Despite generating long maximum distances, the no distance solution actually generates very high locational efficiency with superior measures on most accessibility characteristics. The only exception is the very high total weighted cost, or person-kilometres travelled, indicator which suggests that not including distance constraints in the solution generates the highest transport costs for students.

GIS was further used to vary the distance norms, commencing with 5km and then assessing a 10 km and 15 km distance norm (where school size is fixed), for the criterion of minimizing average distance and for the criterion of maximizing coverage with size constraints. As expected, the modelling of the increase in distance constraint, which effectively means increasing the size of catchment area, generates corresponding increases in person-kilometres travelled for both criteria. Under the criterion of minimizing average distance, the percent of persons aged 14-15 that is covered is very high (at least 94.1%) but there are only marginal increases as the distance norm is allowed to vary to 10 km and then to 15 km. The amount of additional population captured by these solutions is also very marginal. Generally, there is no gain in locational efficiency when going from a distance constraint of 10 km to 15 km.

For the criterion of maximum coverage with size constraints (Table 9), the person-kilometres travelled, number of villages covered, average population covered and other accessibility characteristics are generally lower than for the criterion of minimizing average distance. This results from the nature of the optimization criterion where only the demand points that maximize total captured demand and minimize total weighted impedance are allocated, and these tend to be the closest villages. Villages that are outside of these criteria are not allocated; hence the larger number of non-allocated villages using the criterion of maximizing coverage with capacity constraints.

Tables 8 and 9 also indicate that the average size of catchment areas when using the two criteria are very similar, although the catchment areas are on average larger with the criteria of minimizing average distance. Although the size of catchment areas is below what would be expected using the World Bank (1978) method, the smaller size of catchment area is compensated by significantly higher average population densities.

Table 8: System-Wide Accessibility Characteristics: 75 Optimal Secondary School Locations (Minimizing Average Distance)

Accessibility characteristics	Minimizing Average Distance (Size=160)[a]			
	School Size Norm Fixed - No Distance Criteria	School Size Norm Fixed – 5 km Maximum Distance	School Size Norm Fixed – 10 km Maximum Distance	School Size Norm Fixed – 15 km Maximum Distance
Average distance travelled	3.7	2.8	3.6	3.6
Maximum distance travelled	23.8	4.9	9.9	14.5
Number of villages covered	690	637	690	690
Percent of persons aged 14-15 covered	97.4 (11,651)	94.1 (11,255)	97.4 (11,651)	97.4 (11,651)
Average number of villages per catchment area	9.2	8.5	9.2	9.2
Average number of persons aged 14-15 per catchment area	155	150	155	155
Average population of villages per catchment area	12,088	11,672	11,672	12,088
Average population density per catchment area (p.s.k)	537.3	559.3	537.3	537.3

Average size of catchment area (sq. km)	33.0	28.8	33.0	33.0
Total weighted cost: person-kilometres travelled	36,822	30,364	37,930	36,930

[a] Physical barrier constraints are also included in the objective function.

Maps showing the 75 optimum secondary school locations were presented and discussed previously and are not further discussed here. However, it should be noted that for the 75 optimum secondary school locations the average size of catchment areas ranges between 28 and 33 sq. km – an increase of 5 sq. km as one relaxes the distance norm from 5 km to 10 km, with a similar size of catchment at 15 km. While this is a small catchment area in relation to what might be expected, the catchment areas have much higher densities than what is expected. Therefore, school location planners would also need to consider the distribution of these higher densities in decisions about actual school locations.

Table 9: System-Wide Accessibility Characteristics: 75 Optimal Secondary School Locations (Maximizing Coverage with Capacity Constraints)

Accessibility characteristics	Maximizing Coverage with Capacity Constraints (Size=160)[a]			
	School Size Norm Fixed - No Distance Criteria	School Size Norm Fixed – 5 km Maximum Distance	School Size Norm Fixed – 10 km Maximum Distance	School Size Norm Fixed – 15 km Maximum Distance
Average distance travelled	3.8	2.6	3.0	3.3
Maximum distance travelled	32.7	4.9	9.9	14.4
Number of villages covered	651	557	619	636
Percent of persons aged 14-15 covered	91.6 (10,954)	81.8 (9,782)	88.1 (10,545)	90.0 (10,774)
Average number of villages per catchment area	8.6	7.4	8.2	8.4
Average number of persons aged 14-15 per catchment area	146	130	141	143
Average population of villages per catchment area	11,370	10,154	10,951	11,193

Average population density per catchment area (p.s.k)	537.3	559.3	556.0	551.2
Average size of catchment area (sq. km)	32.9	28.7	27.2	27.9
Total weighted cost: person-kilometres travelled	34,653	23,274	28,578	30,480

[a] Physical barrier constraints are also included in the objective function.

5.1.2 School size model of 340 students

For a secondary school of size 340 students, the analysis of demand by persons aged 14-15 between 2016-2025 indicated that a total of 35 secondary schools would be required across Baksa district. A similar GIS methodology was applied to determine the optimum locations of the 35 secondary schools using the two criteria of minimizing average distance and maximizing coverage with capacity constraints. Tables 10 and 11 present results using similar accessibility characteristics to the 75 optimum location solution.

Table 10: System-Wide Accessibility Characteristics: 35 Optimal Secondary School Locations (Minimizing Average Distance)

Accessibility characteristics	Minimizing Average Distance[a] (Size=340)			
	School Size Norm Fixed - No Distance Criteria	School Size Norm Fixed – 5 km Maximum Distance	School Size Norm Fixed – 10 km Maximum Distance	School Size Norm Fixed – 15 km Maximum Distance
Average distance travelled	2.7	3.1	4.9	6.9
Maximum distance travelled	8.7	4.9	9.9	14.8
Number of villages covered	690	441	631	671
Percent of persons aged 14-15 covered	97.4 (11,651)	70.8 (8,470)	93.0 (11,122)	96.5 (11,546)
Average number of villages per catchment area	19.7	12.6	18.0	19.1
Average number of persons aged 14-15 per catchment area	333	242	318	330
Average population of villages per catchment area	25,903	18,836	24,703	25,661

Average population density per catchment area (p.s.k)	537.3	559.3	558.1	544.7
Average size of catchment area (sq. km)	70.8	61.4	61.5	66.0
Total weighted cost: person-kilometres travelled	31,585	26,378	51,612	70,690

[a] Physical barrier constraints are also included in the objective function.

Table 11: System-wide Accessibility Characteristics: 35 Optimal Secondary School Locations (Maximizing Coverage with Capacity Constraints within 5 Km)

Accessibility characteristics	Maximizing Coverage with Capacity Constraints (Size=340)[a]			
	School Size Norm Fixed - No Distance Criteria	School Size Norm Fixed – 5 km Maximum Distance	School Size Norm Fixed – 10 km Maximum Distance	School Size Norm Fixed – 15 km Maximum Distance
Average distance travelled	6.7	3.0	4.3	4.8
Maximum distance travelled	15.6	4.9	9.9	14.9
Number of villages covered	636	412	562	589
Percent of persons aged 14-15 covered	91.0 (10,885)	66.3 (7,936)	82.4 (9,852)	85.5 (10,233)
Average number of villages per catchment area	18.1	11.7	16.0	16.8
Average number of persons aged 14-15 per catchment area	311	227	281	292
Average population of villages per catchment area	24,220	17,660	21,957	22,772
Average population density per catchment area (p.s.k)	540.0	631.0	564.9	558.8
Average size of catchment area (sq. km)	60.7	34.6	50.0	52.5

Total weighted cost: person-kilometres travelled	68,634	23,224	39,636	43,281

[a] Physical barrier constraints are also included in the objective function.

The above tables show very clearly that with fewer schools, but with a larger school size, the average distance travelled from a village centroid to an optimum location increases; in some cases the increase is more than doubled from 2.7 km to 6.9 km over the four distance constraints that were tested. For the maximum distance travelled, this remains the same due to the actual distance constraint used, except when no distance criteria is used with both criterion. Using the criterion of minimizing average distance, the highest locational efficiency appears to be generated by the 35 optimum location solution that uses no distance constraint. In terms of number of villages covered, percent of demand covered and average population reached, this solution performs better than the other three distance constrained solutions.

Even person-kilometres travelled gives a second best result. However, this solution has placed optimum locations outside of the Baksa village boundaries into a bordering district which is connected by the road layer. In other words, while there is an optimal solution that has been generated, this solution is not feasible for school planning. The solution that uses a 5 km distance constraint is also a very inefficient solution as it only covers approximately two-thirds of the student demand in villages and covers the smallest number of villages. This solution would require additional schools to be planned in villages not covered by the catchments of the 35 optimum locations.

For the maximum coverage with capacity constraints solution, the no distance constraint solution proves to be very inefficient despite maximum coverage of demand and of population. Average distances are significantly longer in this solution and it generates significantly higher person-kilometres travelled compared to the distance constraint solutions. The 5 km distance constraint solution is also very locationally inefficient as only 412 out of 713 (57.7%) villages are served and only 66.6% of persons aged 14-15 are covered by this solution.

It should be further noted that the effect of fewer schools, but with a larger school size, is to effectively double the average size of catchment areas (compared to the 75 optimum location solution). Instead of ranging between 28-33 sq.km they now range from 34-70 sq. km. This is one of the efficiency trade-off associated with fewer but larger secondary schools. What the GIS analysis does indicate (Tables 10 and 11) is that the catchment areas for this school size model are sustainable mainly due to the very high population densities found across the villages.

Figures 11 and 12 show the 35 optimum location solutions using the 10 km distance constraint. With both of these solutions there is one optimum location sited outside the Baksa village boundaries. In the case of Figure 11, the location is in the western part of Baksa, around the Beki River just north of Bhetomare Tup and in the south eastern part of Baksa. However, both of these optimum locations lie very close to the Baksa village boundaries. Also noticeable from Figures 11 and 12 are the numbers of villages not allocated to the optimum locations; 82 and 151 respectively. As was discussed in Section 4, villages which are not allocated would need to be examined by the school planners with a view to possibly adding additional schools to meet the needs of persons aged 14-15 or to implementing a school transport/subsidy scheme for student access to the new secondary school locations. Most of these villages are clustered in the western part and northern central part of Baksa district. In most cases, these villages are outside of the 10 km distance constraint.

5.1.3 School size model of 520 students

For a secondary school of size 520 students, the analysis of demand by persons aged 14-15 between 2016-2025 indicated that a total of 23 secondary schools would be required across Baksa district. A similar GIS methodology was applied to determine the optimum locations of the 23 secondary schools using the two criterion of minimizing average distance and maximizing coverage with capacity constraints. Tables 12 and 13 present results using similar accessibility characteristics to the 75 and 35 optimum location solutions respectively.

The effect of even fewer optimum secondary school locations with larger size generates longer average travel distances compared to the previous solutions; they now extend up to 2.5 km and 7.9 km for the two locational criterion respectively. Catchment area size has also increased substantially and now ranges from 38 to 101 sq. km across the two criteria. Person kilometres travelled has also increased to reflect the longer average distances between village centroids and optimum locations. It is interesting to note that average population density remains fairly constant despite increases in catchment area size.

Figure 11: Optimal Locations of 35 Secondary Schools with Minimizing Distance Criterion

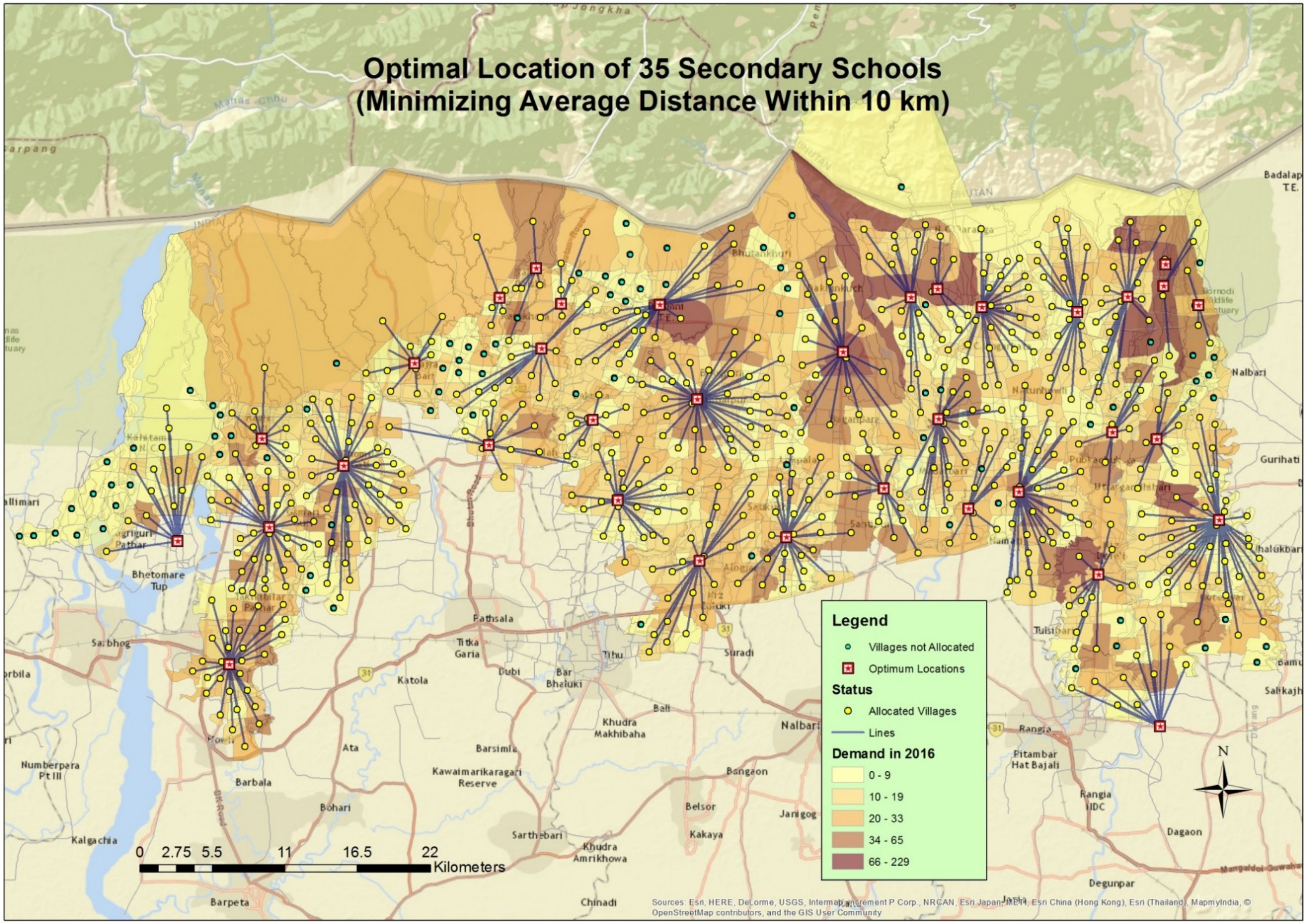


Figure 12: Optimal Locations of 35 Secondary Schools with Maximum Coverage and Minimum Constraints

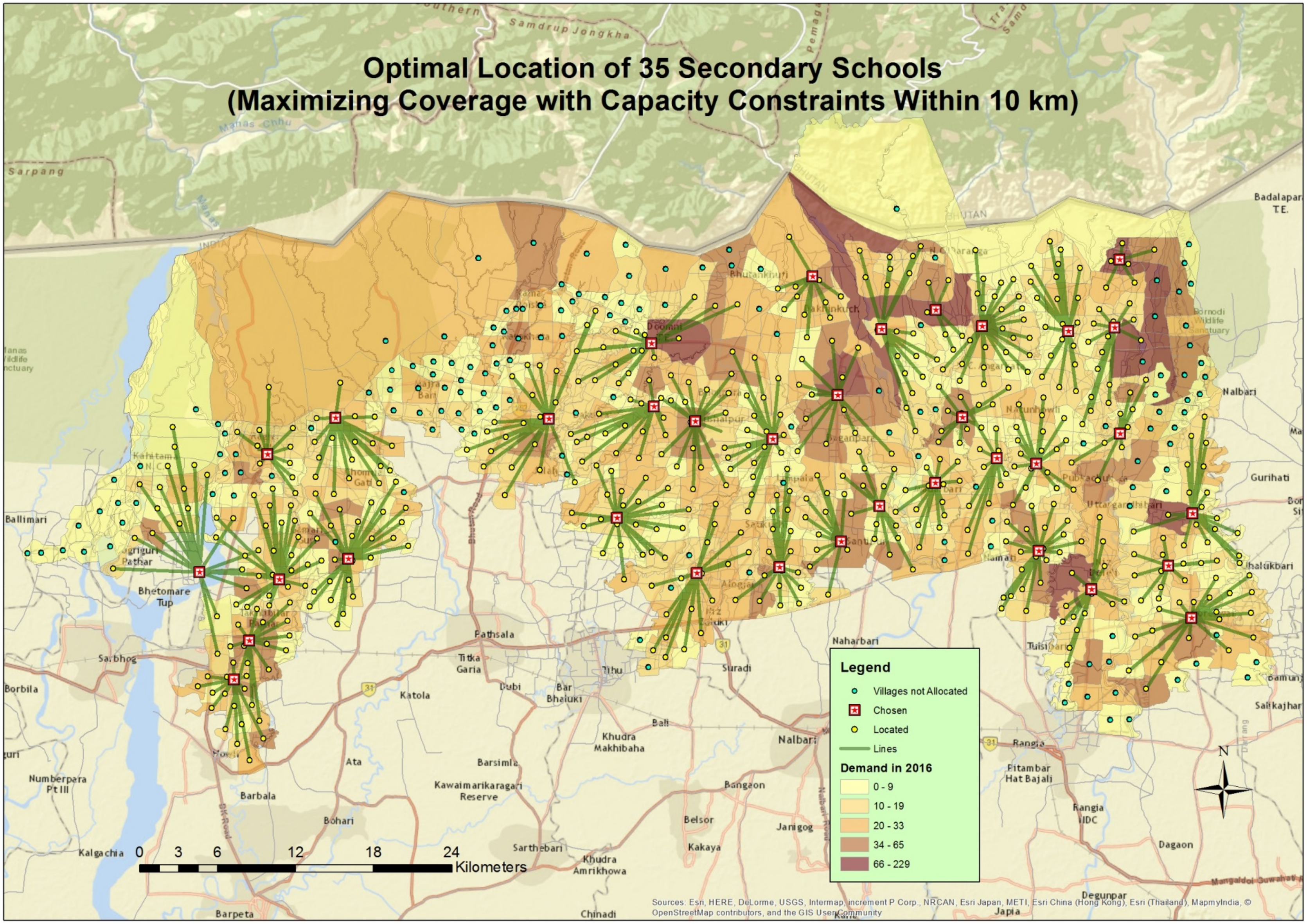


Table 12: System-wide Accessibility Characteristics: 23 Optimal Secondary School Locations (Minimizing Average Distance)

Accessibility characteristics	Minimizing Average Distance[a] (Size=520)			
	School Size Norm Fixed - No Distance Criteria	School Size Norm Fixed – 5 km Maximum Distance	School Size Norm Fixed – 10 km Maximum Distance	School Size Norm Fixed – 15 km Maximum Distance
Average distance travelled	3.9	3.1	5.5	7.5
Maximum distance travelled	10.2	4.9	9.9	14.9
Number of villages covered	678	312	556	629
Percent of persons aged 14-15 covered	96.9 (11,599)	55.2 (6,611)	83.9 (10,032)	92.8 (11,107)
Average number of villages per catchment area	29.4	13.5	24.1	27.3
Average number of persons aged 14-15 per catchment area	504	287	436	483
Average population of villages per catchment area	39,221	22,289	33,903	37,545
Average population density per catchment area (p.s.k)	541.9	679.4	566.7	558.0
Average size of catchment area (sq. km)	101.2	40.7	78.6	89.2
Total weighted cost: person-kilometres travelled	43,241	20,493	52,678	75,866

[a] Physical barrier constraints are also included in the objective function.

Table 13: System-wide Accessibility Characteristics: 23 Optimal Secondary School Locations (Maximizing Coverage with Capacity Constraints within 5 Km)

Accessibility characteristics	Maximizing Coverage with Capacity Constraints (Size=520)[a]			
	School Size Norm Fixed - No Distance Criteria	School Size Norm Fixed – 5 km Maximum Distance	School Size Norm Fixed – 10 km Maximum Distance	School Size Norm Fixed – 15 km Maximum Distance
Average distance travelled	7.9	3.1	5.1	6.1
Maximum distance travelled	66.0	4.9	9.9	14.5
Number of villages covered	609	300	512	564
Percent of persons aged 14-15 covered	88.4 (10,570)	53.0 (6,342)	77.3 (9,250)	82.6 (9,887)
Average number of villages per catchment area	26.4	13.0	22.2	24.5
Average number of persons aged 14-15 per catchment area	459	276	402	430
Average population of villages per catchment area	35,807	21,263	31,327	33,582
Average population density per catchment area (p.s.k)	552.8	684.8	578.6	564.4
Average size of catchment area (sq. km)	82.8	38.8	65.3	70.5
Total weighted cost: person-kilometres travelled	75,713	18,775	43,041	52,997

[a] Physical barrier constraints are also included in the objective function.

In the minimizing average distance solution, the use of no distance constraints generates a very large catchment. This is due to many villages being allocated to just one optimum location outside of the village boundaries; this may be an efficient solution but is not feasible in terms of school planning. The 5 km distance constraint offers an inefficient solution as so many villages and persons aged 14-15 are not allocated to the solution – it is only a good solution if a village is within 5 km. The 10 km distance constraint provides a good compromise in terms of coverage, catchment area and person kilometres travelled.

The maximum coverage with constraints criterion also shows that there are different average distance implications under various scenarios of distance constraints (Table 13). The most inefficient solution appears to be that associated with the use of no distance criteria; this generates the highest average distance and maximum distance travelled and, as a result, the highest person kilometres travelled. Despite this, the no distance constraint solution is able to cover the largest number of villages and highest percent of persons aged 14-15.

Figures 13 and 14 show the optimum locations and their respective allocations for the criterion of minimizing average distance and the criterion of maximum coverage with constraints (10 km solution is shown). For these solutions, the number of villages not allocated to an optimum location is shown in a blue symbol. The non-allocated villages are substantial, irrespective of the distance constraint used for the analysis. In most cases, the non-allocated villages arise because they are outside of the 10 km distance constraint. As indicated previously, one likely implication of this is that additional schools would be required to meet the needs of persons aged 14-15 in non-allocated villages or school transport/subsidy schemes are established to allow for student access to new secondary school locations. For example, in Figure 13, a total of 157 villages are not allocated to an optimum location; this represents a total of 1,926 persons aged 14-15 between 2016-2025 who would not have access to a secondary school. This is equivalent to locating an additional 4 secondary schools (the exact figure is 3.7) of 520 students to cater for this unmet demand. Figure 13 indicates that these additional schools could be located where the main clusters of non-allocated villages are to be found. School planners would not necessarily locate additional schools of 520 students in this exercise; the sizes could be varied to take account of local demand variations.

Figure 14 indicates that a total of 201 out of 713 villages are not allocated to an optimum location (also seen in Table 12), generally for the same reason as identified above. This represents a total of 2708 persons aged 14-15 between 2016-2025 who do not have access to a secondary school. In this case, this is equivalent to locating an additional 5 secondary schools (5.2 to be exact) of 520 students to cater for the unmet need. The locations of the non-allocated villages are similar to those of the previous solution; the western part, the northern central areas, the north eastern and southern parts of Baksa. To repeat, these villages are predominantly outside the 10 km distance constraint or are affected by a physical barrier constraint which means they cannot reach an optimum location due to a river crossing. As mentioned in Section 4, school planners would need to examine each non-allocated village on a case by case basis.

Figure 13: Optimal Locations of 23 Secondary Schools with Minimizing Distance Criterion

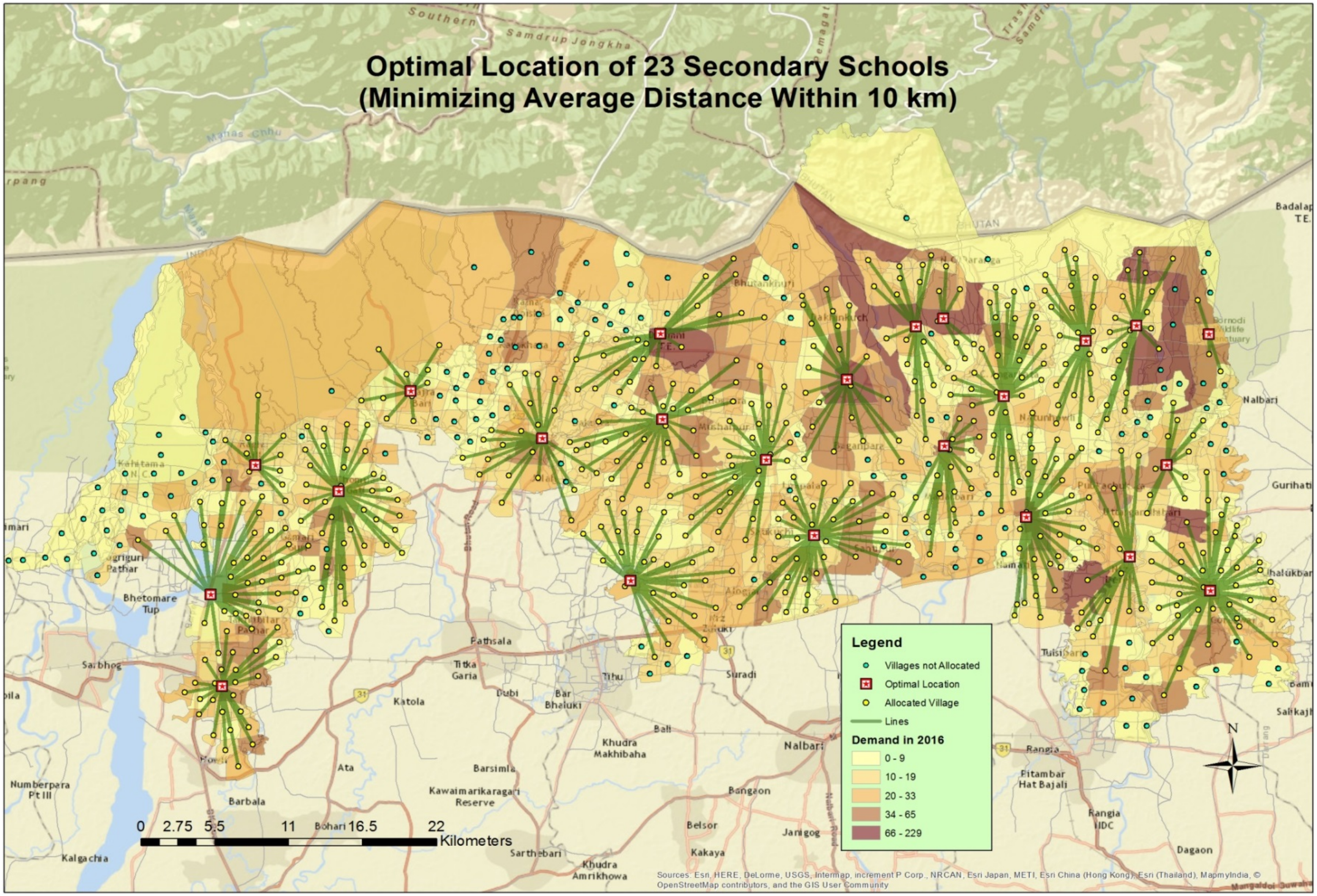
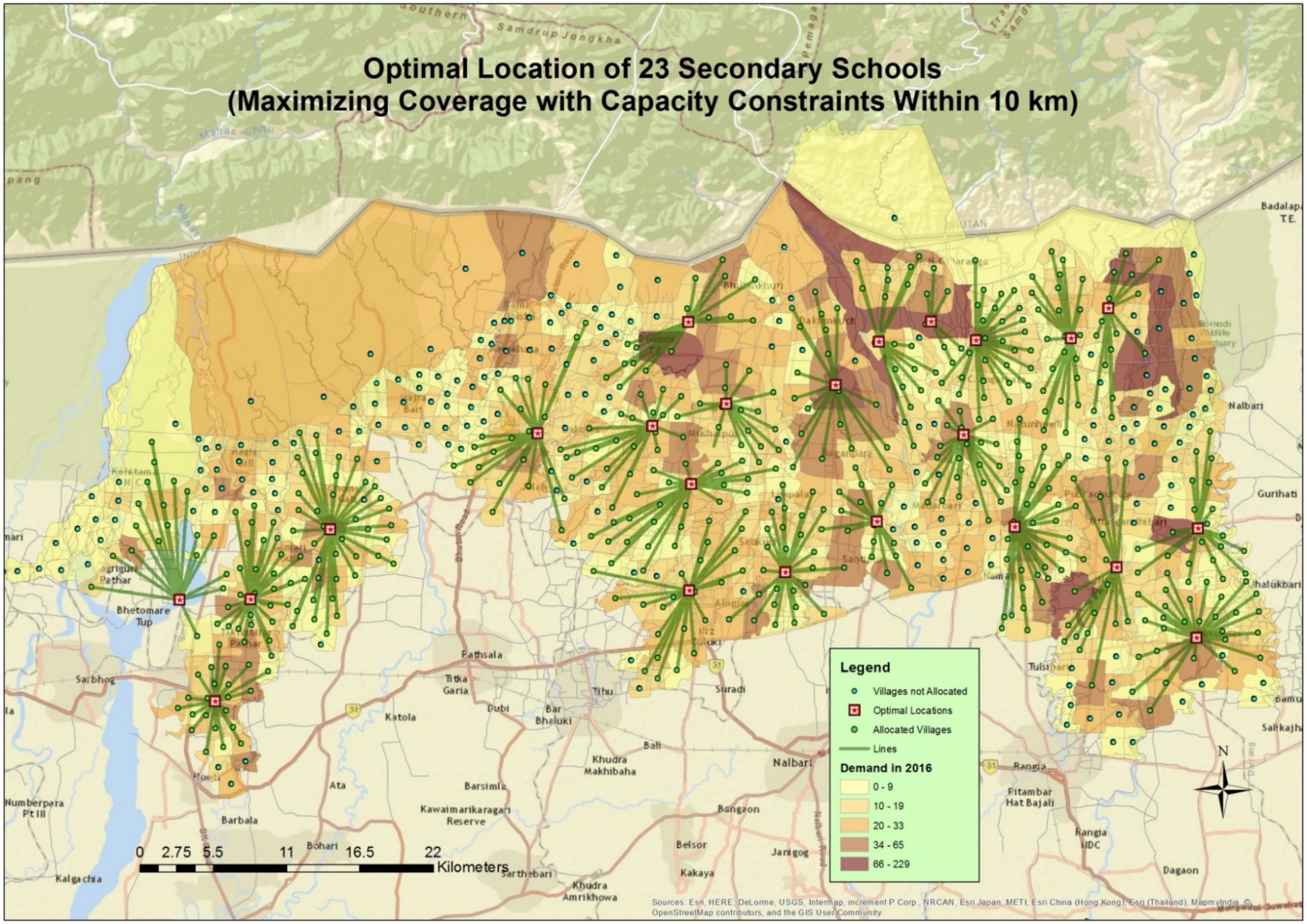


Figure 14: Optimal Locations of 23 Secondary Schools with Maximum Coverage and Minimum Constraints



6. Efficiency and effectiveness trade-offs associated with different methods of school siting

As reported in Sections 4 and 5, the effectiveness associated with relaxing distance norms and using school size criteria to determine school locations is very much dependent on the distance norm chosen and the school size model or scenario selected. The advantage of the GIS analysis is the ability to quantify each scenario and distance norm and compare the results. The following is a summary of the some of the key outputs of the GIS analysis.

6.1 What was learned from section 5?

GIS can be effectively used to model school size scenarios with variations in distance norms with the relevant GIS and non-GIS databases.

Several key implications of relaxing distance norms and using school size criteria:

- As one increases the distance constraint from village centroid to optimum location there is a corresponding increase in average distance travelled, maximum distance travelled, size of catchment areas and other accessibility characteristics,
- There is no maximum distance constraint that allocates all villages to an optimum location.
- As one increases the school size, with the result that there are fewer numbers of larger schools, there is an increase in the number of non-allocated villages to an optimum location.
- Non-allocation of villages is partly due to the number of villages outside of a maximum distance constraint and to the effects of using physical barrier constraints in the GIS analysis (some villages are not allocated as it is not possible to traverse a river to go to the optimum location on the other side).
- Personal kilometres travelled also increases with relaxation of distance constraints and with larger school sizes (which means fewer schools). Personal kilometres travelled may be able to be used by school planners to cost travel to school, especially if a bus scheme were to be introduced to transport students to school (those who live beyond walking distance to a school).
- Non-allocation of villages means either a school transport/subsidy scheme for all villages not allocated and/or location of additional schools of varying size to cater for student demand not allocated.

6.2 What efficiencies are associated with different school size models?

The basic question here is what are the efficiency gains for the education system of having 75, 35 or 23 new secondary schools in optimum locations across Baksa district? The Excel file that accompanies this report **'Projection of Baksa School Needs 2016-2025_v3'** provides estimates of total costs and of resource requirements for a minimum two section lower secondary school (grades 9-10). These basic requirements were provide by the TCA team. Based on the units of room needed per school of size 160, 340 and 520, fixed costs and costs of staffing and operations per school, the grand total costs in Lakhs, Rupees and $USD for providing 75, 35 and 23 schools at a size of 160, 340 and 520 have been calculated as part of the research.

Table 14 is a summary of the cost savings associated with the various models of school size. From Table 14 there are efficiencies for the education system associated with increases in size of school. Total recurrent costs decline, as do grand total costs, as size increases from160, to 340 and to schools of size 520 students. Grand total costs have also been given in $USD to provide relative figures (based on the exchange rate as of 5 November 2015). The decrease in total costs from $USD 7.9 million to $USD 5.6 million represents a 28.2% reduction in total costs.

Table 14: Summary of Costs of Various School Size Models

Size of School	Number of Schools Required	Total Recurrent Costs (Lakhs)	Grand Total Costs 2016-2025 (Lakhs)	Grand Total Costs 2016-2025 (Rupees)	Grand Total Costs 2016-2025 ($USD)*
160	75	1518.86	5202.86	520,285,714	7,913,400
340	35	1361.31	4164.51	416,451,000	6,334,103
520	23	1323.35	3733.52	373,352,429	5,678,586

*Based on the exchange rate as of 5 November 2015.

In terms of resource needs, the Excel file (Costings worksheet) provides a breakdown of units of room required and total resources required for the 75, 35 and 23 schools of size 160, 340 and 520 between 2016 and 2025. This has been summarized in Table 15 below.

Table 15: Total Resources Required 2016-2025

Resources Required	Size of School		
	160	340	520
Number of classrooms per school	4	9	13
Expected Schools	75	35	23
Classrooms	300	315	299
Science lab	75	35	23
Comp.	75	35	23
Art	75	35	23
Library	75	35	23
Toilet	150	140	138
Water	75	70	69
Teachers	375	385	391
HT	75	35	23
Lab att.	75	35	23
Office att.	75	35	23

As indicated in section 5, the three school size models generate fewer demands for resources such as classrooms and teachers, but also fewer resources for other facilities such as science and art labs and toilet and water facilities. The lower number of resources required is in comparison to the current 147 government secondary schools that contain 507 classrooms and 1798 secondary teachers. The total of 375 secondary teachers (for 75 schools of size 160) represents a 79% reduction in the numbers of teachers required to provide lower grade secondary education in the system (Table 15). There is also a corresponding savings in teacher salaries; for example, the 1798 secondary teachers presently in the system are estimated to cost 539.4 million Rupees on an annual basis, whereas 399 teachers (for the 23 schools of size 520) will only require 117.3 million Rupees in salaries on an annual basis – a reduction of 78% in salaries.

It is important to highlight that not only are there efficiencies within and between each school size model, but that the number of schools required for each size model represents fully resourced and fully equipped schools that would provide a quality learning environment for secondary students in which to achieve educational goals. The significance of this point is made all the more relevant if one compares the cost efficiencies in Tables 14 and 15 with the estimated costs of providing basic facilities to those current government secondary schools in Baksa which lack such facilities, and in estimates of recurrent costs for teachers and classrooms. These estimates, which have been calculated using unit costs from the Excel file, are shown in Table 16.

The total costs of providing the six categories of resources needs for government secondary schools where there is a lack is estimated at $USD 3.5 million. These costs are likely to be an underestimate as they do not include other categories of resources that may be required at these 147 schools. For example, according to UDISE 2013-2014, 25 out of 147 (17%) government secondary schools had no playground; 66 out of 147 (44.9%) had no electricity, and; 81 out of 147 (55.1%) had no boundary wall for enclosure and protection of the school. The estimate of $USD 3.5 million would be a one-off cost of providing these resources, but the same schools also have recurrent costs.

Table 16 indicates that the estimated recurrent costs for teachers, classrooms, head teachers, and attendants is in the order of $USD 13.4 million. The estimated total cost to the education system in Baksa is in the order of $USD 16.9 million. This total cost figure is double the total costs from Table 14 of providing 75 schools at size 160 students. As mentioned above, the cost gains of the 75 schools are self-evident when compared to the existing system of 147 government secondary schools, and total costs decline with larger schools of size 340 and 520 students. But, as important, is the fact that these 75 schools are fully equipped and fully resourced to provide a quality learning environment that should enhance learning outcomes and educational goals. There is ample evidence in the education literature on the links between well-equipped education resources and facilities and learning outcomes.

6.3 Other methods of school siting

There are two approaches that school planners can use, with the aid of GIS, to determine other locations of schools in an area. Both approaches involve rationalisation of the government secondary school network:

- Rationalise the network of low enrolment schools
- Rationalise the network of all low enrolment government schools in an area; consolidation into comprehensive schools (grade 1-10).

In both of the above approaches, new schools may result from the process of rationalisation or existing schools may be upgraded with vertical and/or horizontal extensions to cater for the additional students that would be transferred from closed schools.

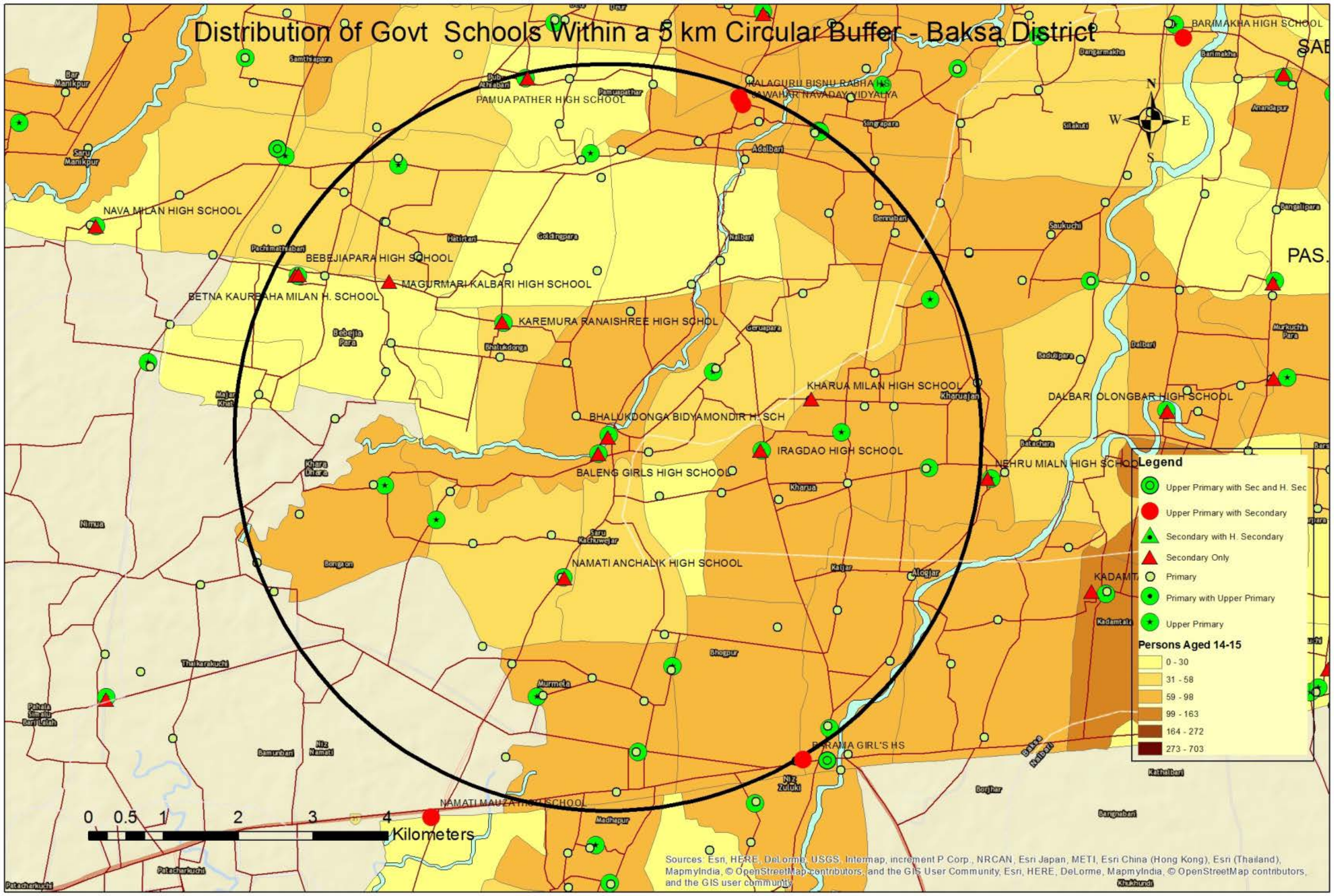
Table 16: Estimates of Resource Needs and Recurrent Costs – Government Secondary Schools Baksa

Resources Required	Number of secondary schools requiring resource (UDISE 2013-2014)	Unit Costs (Lakhs)	Fixed Costs (Lakhs)	Total Costs Rupees	Total Costs $USD*
Science lab	146	7.1	1036.6	103,660,000	1,554,900
Comp.	83	5.0	415	41,500,000	622,500
Art	60	5.0	300	30,000,000	450,000
Library	48	7.0	336	33,600,000	504,000
Toilet	55	4.0	220	22,000,000	330,000
Water	49	0.5	24.5	2,450,000	36,750
Total				**233,210,000**	**3,498,150**
Recurrent Costs	Total for all secondary schools	Unit Costs Rupees		Total Costs Rupees	Total Costs $USD
Teachers	1798	25,000		539,400,000	8,091,000
Classrooms	507	563,000		285,441,000	4,281,615
HT	120	25,000		44,100,000	661,500
Lab att.	147	7,000		12,348,000	185,220
Office att.	147	7,000		12,348,000	185,220
Total				**893,637,000**	**13,404,555**

*Based on the exchange rate as of 5 November 2015.

GIS can be used to assist with this process. Figure 15 provides an example of an area of Baksa district which contains a number of schools within a 5 km circular buffer. This area was selected as there are secondary schools located where there is relatively low demand (persons aged 14-15) for secondary education. There are many such areas that can be identified with GIS across Baksa district.

Figure 15: Distribution of Government Schools with a 5 Km Circular Buffer



The buffer area shown in Figure 15 indicates that there are many primary schools and upper primary schools. Importantly, the area contains 10 secondary schools and two upper primary schools with secondary schools. The two upper-primary with secondary schools are located in the top part of the buffer area (just north of Adalhari). These two schools contain 190 and 12 elementary enrolments respectively. GIS analysis of the UDISE data for these twelve schools indicates that they contain 1052 students and a total of 53 secondary classrooms. The estimated classroom capacity of these schools is 2120 classrooms (53 classrooms @ 40 students per classroom). Based on this information, it can be determined that the school utilisation rate of these 12 schools is only 49.6% - largely due to low enrolments.

Table 17 provides a summary of the twelve schools, together with some key attributes of enrolment and classrooms. All are co-educational schools except for Baleng Girls HS. Eight out of the 10 secondary schools have enrolments between 41 and 79 students – an indicator of the low enrolment status of schools in this particular area. The classroom capacity indicator highlights that these schools, with the exception of Magurmari Kalbari HS, have a very low level of school utilisation; they have an excess capacity of student classroom space. In addition, most of these schools have an excess number of secondary teachers for the size of school. Some of these schools are candidates for rationalisation.

Table 17: Secondary Schools within a 5 Km Circular Buffer

Secondary School	Sec. Classrooms	Sec. Teachers	Sec. Students	Capacity	Student-Teacher Ratio
Bebejiapara HS	2	9	64	240	26.7
Betna Kaurbaha Milan HS	4	12	53	160	33.1
Namati Anchalik HS	5	14	66	200	33.0
Baleng Girls HS	2	7	55	80	68.8
Bhalukdonga Bidyamondir HS	4	18	73	160	45.6
Magurmari Kalbari HS	7	19	225	280	80.4
Karemura Ranaishree HS	2	9	79	240	32.9
Pamua Pather HS	3	8	66	240	27.5
Iragdao HS	2	10	72	240	30.0
Kharua Milan HS	3	12	41	120	34.2
Kalaguru Bisnu Rabha HS (Upper Primary with Secondary)	2	5	250	80	50.0
Jawahar Navaday Vidyalya HS (Upper Primary with Secondary)	2	5	8	80	16.0

Given the distribution of secondary schools shown within the 5 km buffer, with characteristics as in Table 17, it is possible to suggest schools that can be rationalised (closed in this case) and students transferred to another nearby school. In this exercise, GIS is useful as the detailed roads layer is available (Figure 5) to assist in ensuring that norms of distance from home to school are maintained in the rationalisation proposals. These distance norms could also be varied by the school planners.

From Table 17 and Figure 15, the following proposals could be suggested for merger:

- Closure of Jawahar Navaday Vidyalya HS and transfer of 8 students to Kalaguru Bisnu Rabha HS; No effect on student travel to school; Surplus teachers = 2-3
- Closure of Kharua Milan HS and transfer of 41 students to Iragdao HS; Additional 1.2 km of travel to Iragdao HS; Surplus teachers =12
- Closure of Baleng Girls HS and transfer of 55 students to Bhalukdonga Bidyamondir HS; Very minor increase (500 metres) in student travel to school; Surplus teachers = 7
- Closure of Betna Kaurbaha Milan HS and transfer of 53 students to Bebejiapara HS; No effect on student travel to school; Surplus teachers = 12.

Other proposals could also be generated from Figure 15 and Table 17 but distance from home to school norms would need to be varied. Based on the above, the proposals suggest that, as a minimum, there would be 34 secondary teachers that are surplus to education requirements. In teacher salaries alone, these proposals would generate a savings of 10.2 million Rupees annually in teacher salaries (assuming an annual salary of 25000 Rupees). There could be additional potential savings in teacher salaries given that there are also surplus teachers in the schools that are the recipients of students from school which would be closed. For example, Magurmari Kalbari HS, which currently has an enrolment of 225 students, has a complement of 19 secondary school teachers. However, based on teacher unit requirements by size of school prepared by TCA, this school should have no more than 8 teachers at the school; therefore 11 teachers are surplus to needs and this is equivalent to 3.3 million Rupees annually in teacher salaries.

The second approach to school siting could be to merge primary, upper primary and secondary schools in the area to form a comprehensive school from grades 1-10. This could either be a new school which is located in close proximity of these other schools (using school planning norms) or an existing school with sufficient excess capacity to accept the transfer of students to its classrooms. As with the previous approach, GIS could be used to identify candidate schools for merger/closure and transfer of students to a 'new' comprehensive school.

From Figure 15, the following schools could be merged into one comprehensive school (grade 1-10):

- Closure of Betna Kaurbaha Milan HS and transfer of 53 students to Bebejiapara HS; Closure of Bebejiamara Upper Primary School and transfer of 70 students to Bebejiapara HS; Closure of Bebejiapara Local Primary School and transfer of 45 students to Bebejiapara HS. Very minimal effect on primary student travel to school (410 metres increased travel); Bebejiapara HS has capacity to become a comprehensive school with total enrolments of 232 students and a capacity of 240 students (Table 17).
- Closure of Karemura Upper Primary School and transfer of 69 students to Karemura Ranaishree HS; 805 Karemura Local Primary School and transfer of 43 students to Karemura Ranaishree HS; Very minimal effect on primary student travel to school (650 metres increased travel); Karemura Ranaishree HS has capacity to become a comprehensive school with total enrolments of 191 students and a capacity of 240 students (Table 17).
- Closure of Cheunipam Local Primary School and transfer of 33 students to Bhalukdonga Bidyamondir HS; Closure of Bhalukdonga Bidyamondir Upper Primary School and transfer of 86 students to

Bhalukdonga Bidyamondir HS; Minimal effect on primary student travel to school (770 metres increased travel); Bhalukdonga Bidyamondir HS has capacity to become a comprehensive school with total enrolments of 192 students (Table 17). However, this would require the addition of an extra classroom of 40 students given the capacity of the present school of 160 students.

- Closure of Kharua Milan HS and transfer of 41 students to Iragdao HS; Closure of Iragdao Upper Primary School and transfer of 93 students to Iragdao HS; Additional 1.2 km of travel to Iragdao HS; Iragdao HS has capacity to become a comprehensive school with total enrolments of 206 students and a capacity of 240 students (Table 17).

The above examples, which are not comprehensive by any means, demonstrate that by using GIS it is possible to contemplate scenarios for creation of comprehensive schools in this particular area. Needless to say, this exercise could be repeated for other areas across Baksa district by using GIS to co-locate government schools of interest and to filter these schools by low enrolments and other efficiency indicators.

7. GIS information used to optimize school resourcing for ensuring maximum efficiency

The information presented in previous sections highlights that GIS can not only be used for analytical modelling of various scenarios, but can also be used to monitor school and education resourcing. For example, several of the Figures presented so far in the report visualise the distribution of school indicators or other attributes of demand from the census file. Maps of school utilisation rates, enrolment size and demand, 5km buffers around government secondary schools and the spatial distribution of various types of government secondary schools provide school planners and policy makers with a view of current resourcing. More importantly, these types of maps highlight problems in the distribution of resources and the likely need for policy interventions to redress resource allocation issues. Most of these visualisations have been based on the UDISE 2013-2014 data.

Fortunately, the same school data contains a myriad of other school attributes that can be visualised for the same purposes. For example, attributes of teacher qualifications, presence /absence of boys and girls toilets in schools, presence/absence of a library and electricity, playground and water facility in schools provides the raw data that can be used by GIS with a layer of secondary school locations to map the distribution of these resources.

The maps that appear in the following pages take the attributes in the UDISE data and visualise the distribution of the phenomena. Figure 16 shows the distribution of schools that have or do not have both boys and girls toilets present in respective secondary schools. There are 46 secondary schools that do not have both a boys and a girl's toilet – a surprisingly large number of schools considering that the majority of secondary schools are co-educational. Figure 17 indicates those schools that do or do not have electricity on their site. Again, a surprisingly large number of government secondary schools in Baksa are without electricity.

The UDISE data contains an attribute that attempts to measure the total number of facilities present in schools. It is a composite measure of facilities and is made up of the presence/absence of both boys and girls toilets, electricity, water facility, library and playground. The maximum value for any school is 5 – all 5 facilities are present in a school. Figure 18 highlights patterns in the distribution of the total number of facilities in government secondary schools. Two schools in the eastern part of Baksa have none of the 5 facilities, and there is a spread of secondary schools with just one of the 5 facilities. Figure 18 clearly shows that there are serious problems with inequities in the distribution of education facilities in schools. This would require attention by school planners to ensure that all school have the required facilities for students. Figure 18 further highlights that there is a serious lack of homogeneity in the quantity (and possibly quality) of facilities in secondary schools. This, in turn, has implications for allocation of resources to achieve a more homogenous distribution of infrastructure for education purposes in the district.

The academic qualifications of teachers in government secondary schools are an indicator of quality of the education system. The data allows for the mapping of various academic qualifications, but only the number of teachers with academic qualifications at graduate level or above is mapped here (Figure 19). This map highlights that there is wide variation across government secondary schools in the numbers of teachers with academic qualifications at graduate level or above. The schools with the least number of teachers with this qualification are predominantly found in the central and eastern parts of Baksa.

Figure 16: Distribution of Secondary Schools with Both Boys and Girls Toilets

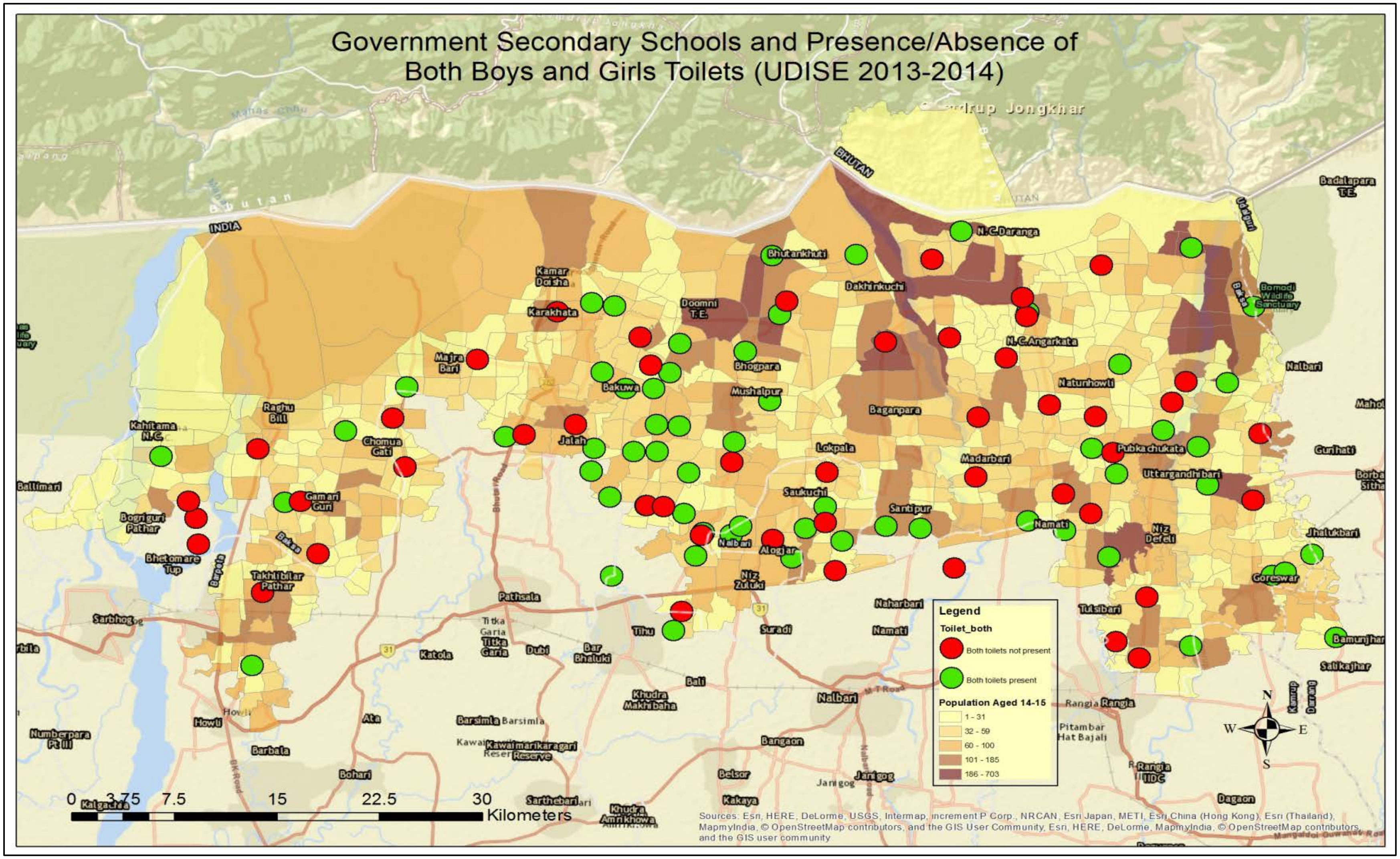


Figure 17: Distribution of Secondary Schools with and without Electricity

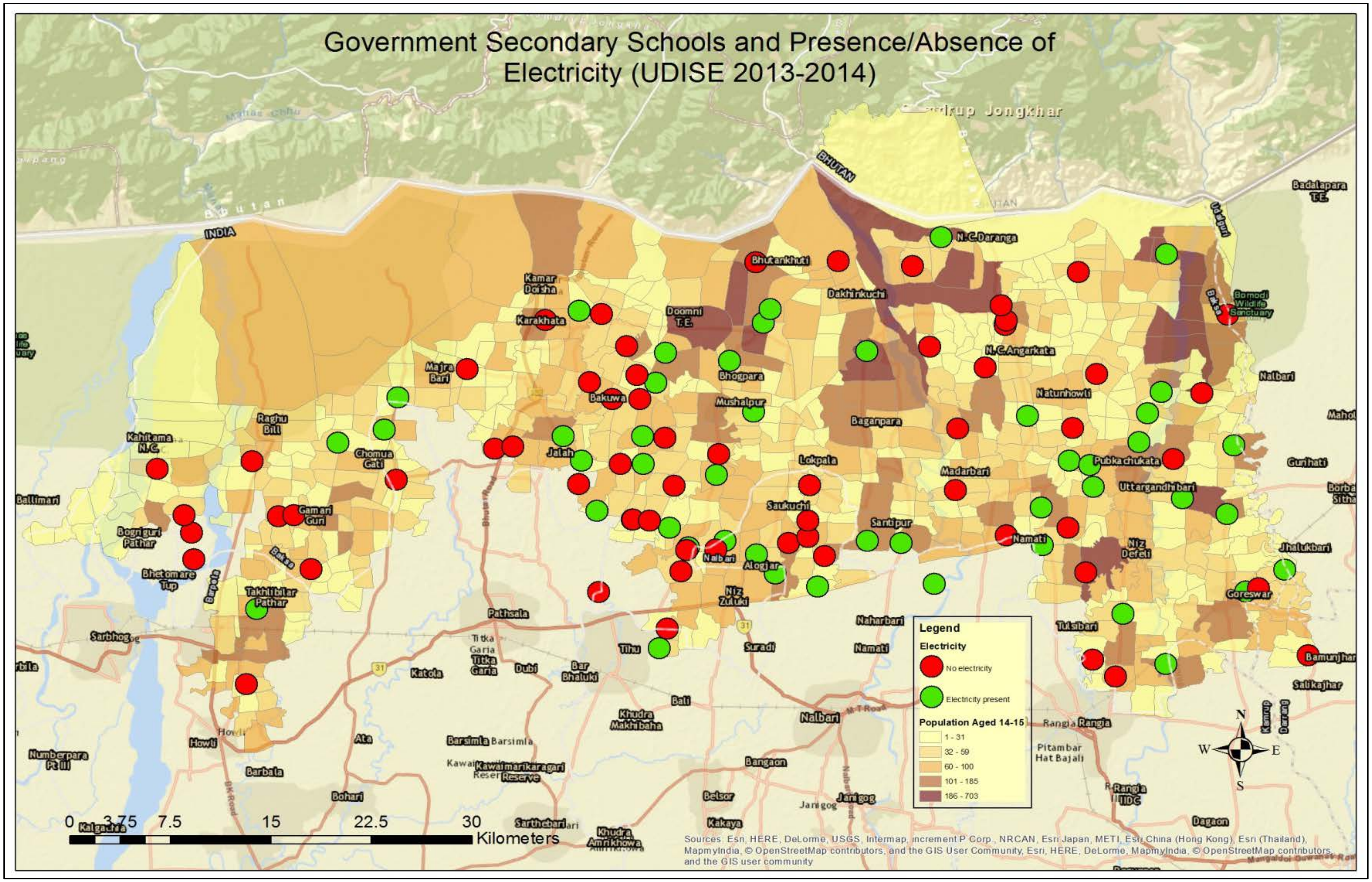


Figure 18: Distribution of Secondary Schools and Total Number of Facilities Present

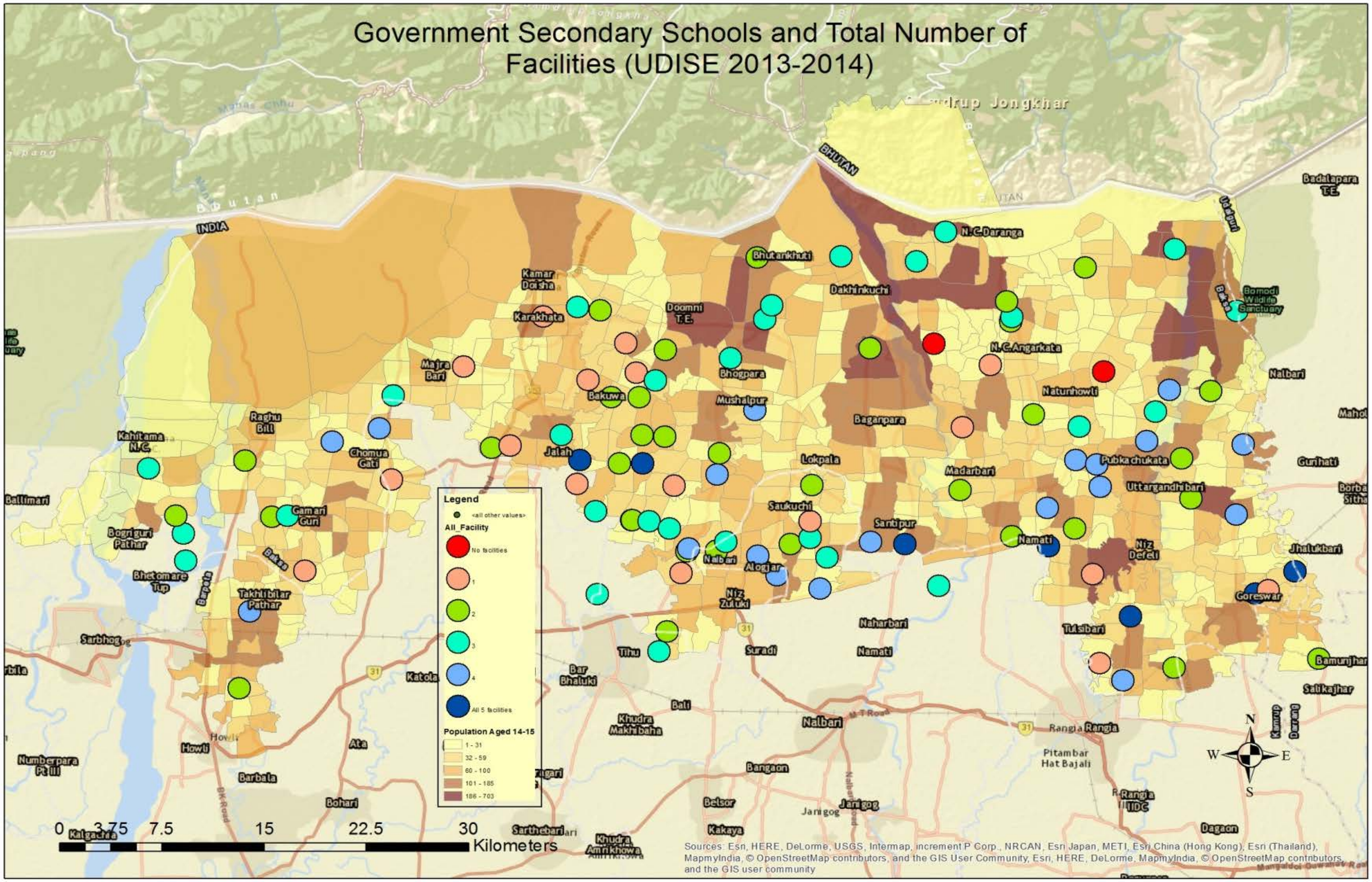


Figure 19: Distribution of Secondary Schools and Number of Teachers with Academic Qualifications at Graduate Level or Above

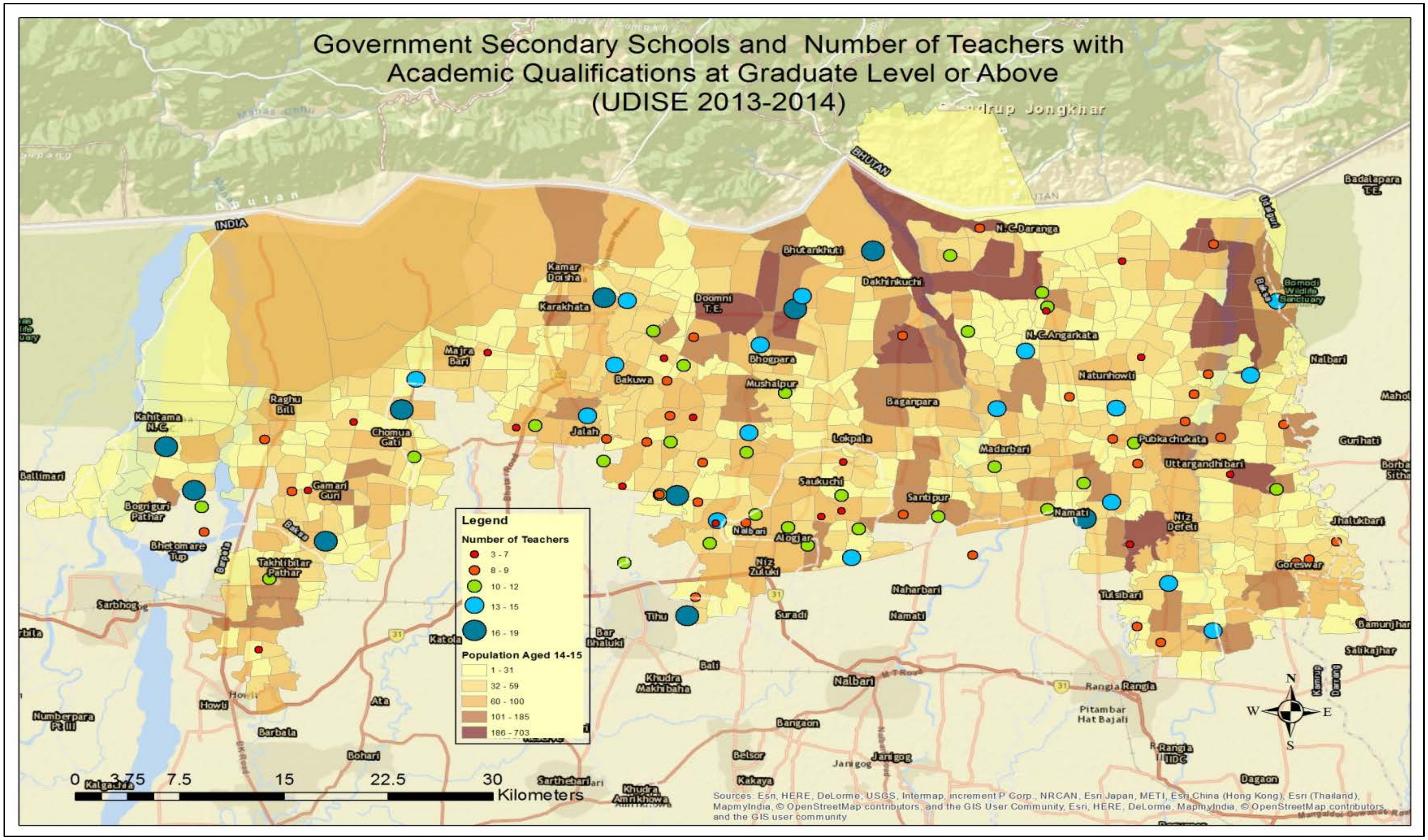


Figure 20: A Network Based Service Area of 5 Km around a Secondary School

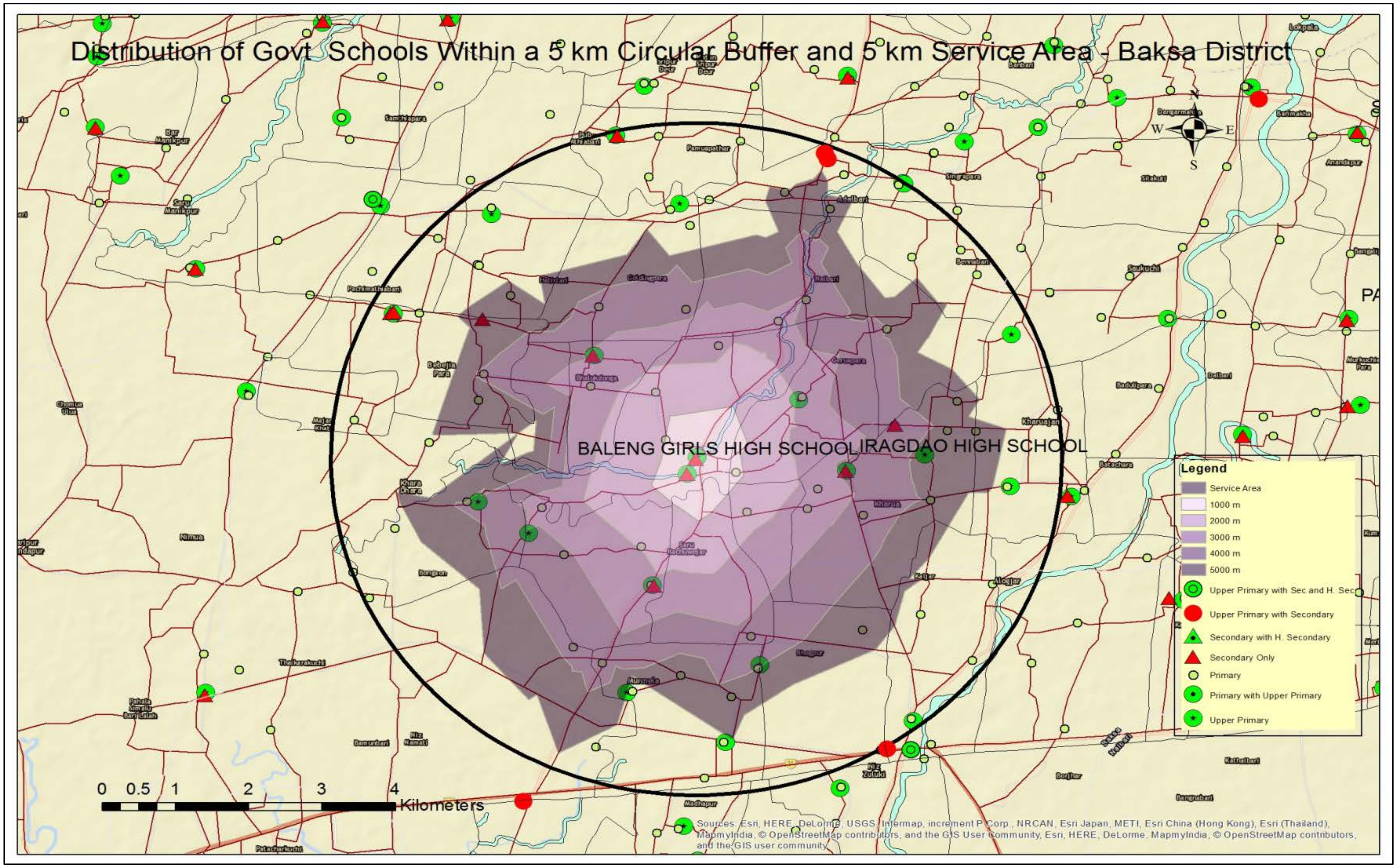
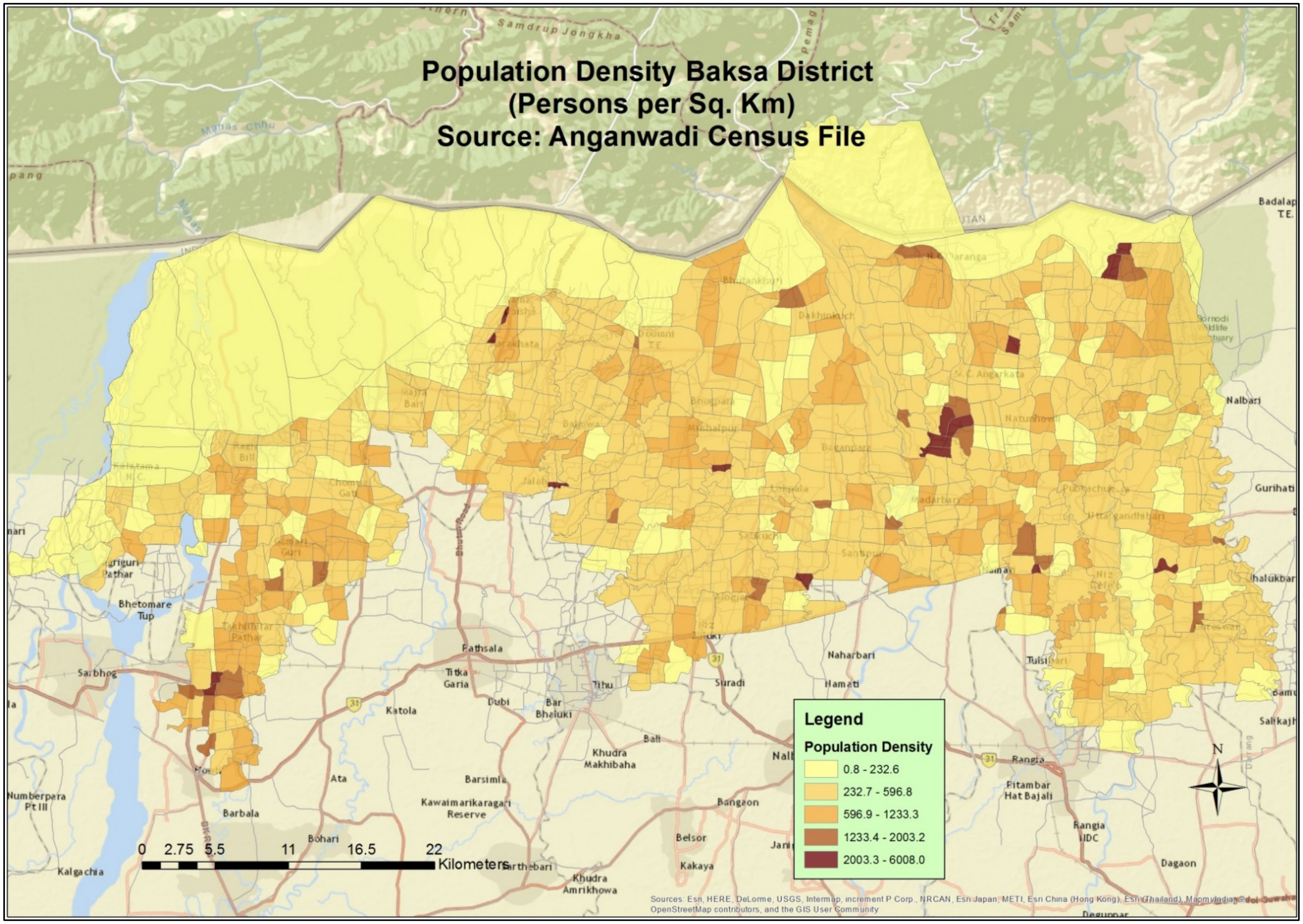


Figure 21: Distribution of Population Density of Baksa Villages



The service area map around a government secondary school displayed in Figure 20 is not of itself an education resource but rather a measure of efficiency in the distribution of schools. The service area shows 1000m, 2000m, 3000m, 4000m and 5000m distance bands around a school that are generated from the detailed road layer distances. These are more realistic depictions of distances around a secondary school, as compared to the circular 5km buffer, and could be used to plan for additional schools in unserved areas; thereby ensuring that the spacing between any new schools properly reflects the school planning norms of distance.

Finally, the map of distribution of population density (Figure 21) provides school location planners with another view of the distribution of total population and of demand for educational resources. Figure 21 indicates that there is a large amount of uniformity on the distribution of population density across Baksa, with only relatively few villages having very high population density. A density map, coupled with the distribution of persons aged 14-15, provides planners with a basic understanding of the distribution of demand for secondary education in Baksa and of the interrelationship between location of secondary schools and demand. The point has already been noted in Section 3 that, generally, there are many government secondary schools in Baksa located in areas of low demand for secondary education – one of the key reasons for low enrolments and low student-teacher ratios.

In sum, the sets of maps that have been produced above, and those that could be produced with the use of GIS, allow school planners to both interrogate issues of school resourcing and to identify remedial strategies for improving the efficiency of the education system. The maps produced so far indicate that there is much work to be undertaken in Baksa district to improve school resources and efficiency of the secondary education system. Visualisation of school resource attributes is the first step toward understanding the magnitude and scale of any problems, and a generator of solution strategies for improved efficiency.

8. Policy implications of research findings

The key findings of the research into the four questions posed at the beginning raise some potential implications for education policy makers at both the state and district levels, and possibly at national level as well.

One of the key concerns expressed in the introductory paragraph of the research paper is that the 5 km distance norm has not been applied consistently, or has not considered geographic constraints and population distribution, and has led to inefficient and often inequitable distribution of education resources. The GIS analyses undertaken for this research have indicated that this concern is valid in the case of Baksa district. Analysis of school data, village level data and attributes of the secondary education system show that there is a close spacing of government secondary schools and, in many instances, co-location with other types of government schools. In addition, the close spacing is linked with low enrolments and other inefficiencies in the school system. The secondary education system as it exists at present, is the cumulative result of a myriad number of school location decisions that generally do not follow the 5 km norm, they are much closer to a 2 km norm.

The implication for policy makers is that the size and spacing of secondary schools must be examined more seriously than in the past in future decisions about new schools or rationalisation of existing schools. The GIS based evidence presented in the paper even suggests that had the 5 km norm been adhered to, as intended, the proliferation of inefficiencies would be less than is the case at present. Therefore, standardisation and implementation of school location planning policy should be carefully monitored at national, state and district levels. Schools should be located in areas of demand, even if this means relaxing the distance norms.

This means that policy makers should understand the distribution of present and future demand and align school location policies with demand characteristics while, at the same time, adhering to principles of school size and distance norms. This research has demonstrated how GIS can be used as a tool for diagnosis of the education system and for analysis of scenarios that are linked to improved efficiencies in the distribution of education resources.

Following from this, it is important for policy makers to foster utilisation of GIS technology for school location and education planning and management decision making. Central to this sue of GIS is the availability of appropriate GIS layers for the education sector and of valid school data for analysis. The general impetus for policy makers should be to promote establishment of GIS cells or units in MoE at state and district levels. This would, over a period of time, facilitate integration of key sources of both GIS and non-GIS databases that enable a more analytical and scientific approach to school location planning decisions.

The modelling of scenarios on relaxation of school size and distance norms has provided the quantitative evidence of impacts of such scenarios on average distance travelled and catchment area size. The greater efficiencies and savings achieved with fewer but larger schools are substantial as compared to the existing education system. In moving from a school size of 160 to 340 and then 520 presents policy makers with economies of scale and better utilisation of education resources. This research has quantified the savings of each school size scenario.

An important trade-off emerges with economies of scale in schools size – increasing distance from home to school and the requirement for larger catchment areas. What the GIS analysis of optimum locations and optimum allocations is that it is possible to plan for alternative school size and distance constraints for the education system. By varying school size scenarios and distance constraints from 5 km to 15 km it has been shown that such variations lead to sustainable school catchment areas and that there are optimal locations for new secondary schools that minimise distances and maximize coverage to the population in demand.

For policy makers, one of the impacts of longer average distances to school and of larger catchment areas is that beyond a certain acceptable distance, there may need to be consideration of additional schools and of the introduction of school transport/subsidy schemes to cater for the needs of students in villages beyond the new distance norm (that are not allocated to the new optimum secondary school locations) or even for those within the new distance norm.

Policy makers should examine evidence of the impacts of school restructuring in China (especially rural China) to understand the context for the introduction of school transport or transport subsidy schemes for students in rural villages. Rationalisation of the primary and secondary education system s in China has generated large scale efficiencies in the school system as economies of scale associated with fewer but larger schools positively impact resource allocation and education spending.

The trade-off in China, as has been demonstrated in the present GIS analysis, is longer average distances and larger catchment areas that affect access to the larger schools (Zhao and Parolin, 2011; Zhao and Parolin, 2012; Zhao and Parolin, 2014). School transport subsidies to rural families, especially poorer farming families, allowed students to access the education system. Another policy initiative that stemmed from school rationalisation to fewer but larger schools was the introduction of boarding facilities at schools. This has not been suggested in previous sections of the research report, but is another policy initiative that should be considered if moving to alternative schools sizes and distance norms.

In addition, the research has shown that fewer, but larger, schools is also possible with the existing distribution of schools; it is not solely a function of new school locations. As in China, it has been shown that it is possible to rationalise the secondary school system, and broader school system, to create fewer but larger schools with improved efficiencies and minimal distance trad-offs. Examples were also given of scenarios where it is possible to consolidate schools to create larger sized comprehensive schools with improved efficiencies. It is up to policy makers at national, state and district levels to begin to embrace these scenarios, as occurred in China, in order to generate a more effective and standardised education system.

9. Conclusions

By way of concluding comments, it is pertinent to again highlight that this research has, firstly, demonstrated how GIS can be effectively used to diagnose and analyse the education system of a district. The same GIS methodology, and GIS and non-GIS data, could be applied in other districts and at state and national levels. If anything, it is hoped that this report will boost the likelihood of this technology being used in future school planning work at these levels. This, in turn, may require setup of training programs and specialised units within the structure of a MoE.

Finally, the research has also demonstrated that it is possible to think about alternative school size and distance norms, and to use the technology to document the efficiency and effectiveness trade-offs, and cost savings, that could occur as a result. It has been demonstrated that the 5 km distance norm is, indeed, a problem for the education system and that alternative scenarios exist. It is now up to the policy makers and school planners to respond to these scenarios.

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Annexure 1: Technical Appendix

The location-allocation algorithm used for the tasks presented and discussed in Sections 4 and 5 of the Report has been implemented using the Location-Allocation procedures in the Network Analyst extension of ArcGIS 10.3.1.

The location algorithm works by identifying an optimum set of new school locations from a pool of candidate locations (nodes on a road network), given the objective functions of (1) minimizing the total cost of all distances travelled (P-median problem), where distance is the length of road segments in metres on the road network, and (2) maximizing coverage to the population subject to capacity constraints. The allocate algorithm works by assigning existing or future student demand in a particular village in a least cost path commencing from the optimum school locations and growing outwards. Allocation modelling assigns students from surrounding localities to the nearest existing, or optimum, schools until the maximum capacity of respective schools is reached. The allocation procedure assumes that the locations of schools are fixed.

The mathematical formulation of the location-allocation function that minimises the total distance travelled overall by students to their nearest school is given below (Moller-Jensen, 1998):

$$\text{Min } Z = \sum_{i=1}^{n} \sum_{j=1}^{m} w_i \, d_{ij} \, x_{ij} \quad \text{(Revelle and Swain, 1970)}$$

subject to:

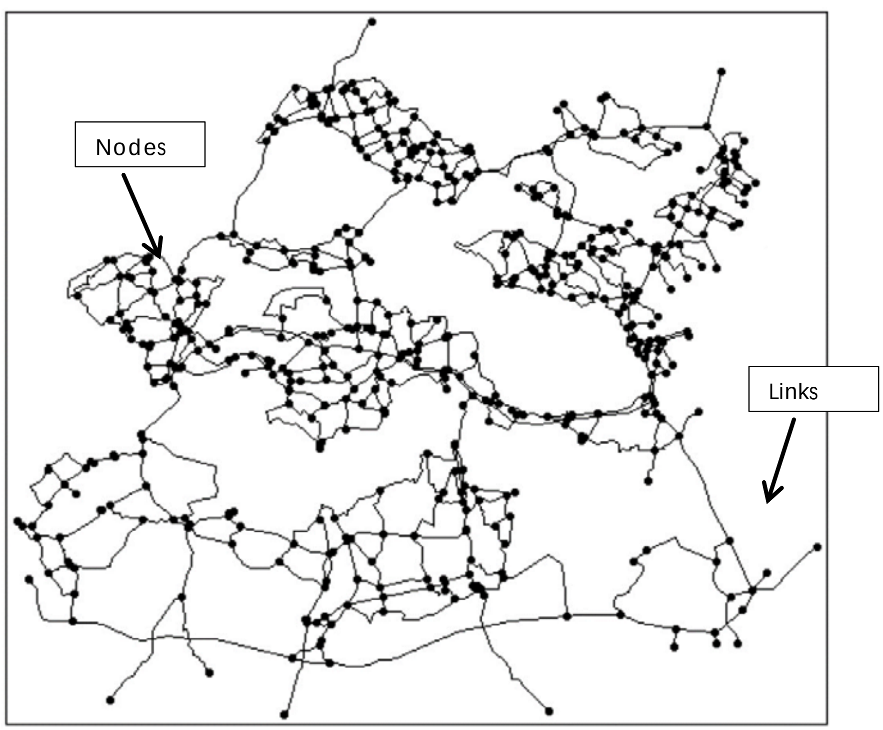
1) $\sum_{(j=1,m)} y_j = p$
(restricts the number of schools to p)
2) $\sum_{(j=1,m)} x_{ij} = 1, \forall\, i$
(ensres that every demand location i is served)
3) $y_i >= x_{ij}, \forall\, i, \forall\, j$
(node i can assign to j only if there is an open facility at j; if $x_{ij} = 1$ then $y_{ij}=1$)

where: i = demand location
j = candidate facility location
n = number of demand location
m= number of candidate facility locations
p = number of facilities to locate
w_i = demand at node i
d_{ij} = shortest distance between demand location i and candidate j
y_i = binary variable: 1, if facility is located at site j, 0, otherwise
x_{ij} = binary variable: 1, if demand location i is served by facility at site j, 0, otherwise

The above formulation is a solver used by the Location-Allocation procedures in Network Analyst to solve for the facility location problem. According to the Network Analyst Tutorial (ESRI, 2010), given m candidate facilities and n demand points with a weight (estimated persons aged 14-15 in 2016), choose a subset of the facilities, p, such that the sum of the weighted distances from each n to the closest p is minimized. This is a combinatorial problem of the type N Choose P, and the solution space grows extremely large. The tutorial goes on to indicate that, 'Optimal solutions cannot be obtained by examining all the combinations. For example, even a small problem like 100 choose 10 contains over 17 trillion combinations. In addition, the location-allocation solver has options to solve a variety of location problems such as to minimize weighted impedance, maximize coverage, or achieve a target market share. Heuristics are used to solve the location-allocation problems (ESRI, 2010).

'The location-allocation solver starts by generating an origin-destination matrix of shortest-path costs between all the facilities and demand point locations along the road network. It then constructs an edited version of the cost matrix by a process known as Hillsman editing. This editing process enables the same overall solver heuristic to solve a variety of different problem types. The location-allocation solver then generates a set of semi-randomized solutions and applies a vertex substitution heuristic (Teitz and Bart) to refine these solutions creating a group of good solutions. A metaheuristic then combines this group of good solutions to create better solutions. When no additional improvement is possible, the metaheuristic returns the best solution found. The combination of an edited matrix, semi-randomized initial solutions, a vertex substitution heuristic, and a refining metaheuristic quickly yields near-optimal results' (ESRI, 2010).

Location-allocation modelling relies on a network such as a road network which is structured in terms on nodes (facility locations and demand locations) and links (edges) that capture the distance or cost of moving from node to node. The following graphic shows an example of a road network.

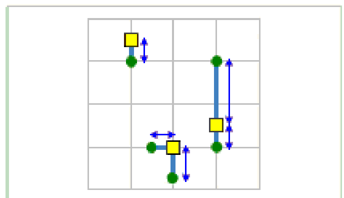


A more detailed description of the two optimality criterion used in the Location-Allocation analysis for this report are shown in the table below which is taken from the Network Analyst Tutorial.

Location-allocation problem types

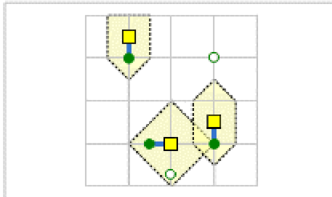
<table>
<tr><th>Problem type</th><th>Description</th></tr>
<tr><td>Minimize Impedance

(P-Median)</td><td>Facilities are located such that the sum of all weighted costs between demand points and solution facilities is minimized. The arrows in the graphic below highlight the fact that allocation is based on distance among all demand points.


Minimize Impedance chooses facilities such that the sum of weighted impedances (demand allocated to a facility multiplied by the impedance to the facility) is minimized.

This problem type is traditionally used to locate warehouses, because it can reduce the overall transportation costs of delivering goods to outlets. Since Minimize Impedance reduces the overall distance the public needs to travel to reach the chosen facilities, the minimize impedance problem without an impedance cutoff is ordinarily regarded as more equitable than other problem types for locating some public-sector facilities such as libraries, schools, regional airports, museums, department of motor vehicles offices, and health clinics.

The following list describes how the minimize impedance problem type handles demand:
• If an impedance cutoff is set, any demand outside all the facilities' impedance cutoffs is not allocated.
• A demand point inside the impedance cutoff of one facility has all its demand weight allocated to that facility.
• A demand point inside the impedance cutoff of two or more facilities has all its demand weight allocated to the nearest facility only.</td></tr>
<tr><td>Maximize Capacitated Coverage</td><td>Facilities are located such that as many demand points as possible are allocated to solution facilities within the impedance cutoff; additionally, the weighted demand allocated to a facility can't exceed the facility's capacity.</td></tr>
</table>

	 Maximize Capacitated Coverage behaves like either the Minimize Impedance or Maximize Coverage problem type but with the added constraint of capacity. (If **Impedance Cutoff** is set to **<none>**, it behaves like a capacitated version of Minimize Impedance.) You can specify a capacity for a facility by assigning a numeric value to its Capacity property. If the Capacity property is null, the facility is assigned a capacity from the **Default Capacity** property of the analysis layer. Use-cases for Maximize Capacitated Coverage include creating territories that encompass a given number of people or businesses, locating hospitals or other medical facilities with a limited number of beds or patients who can be treated, or locating warehouses whose inventory isn't assumed to be unlimited. The following list describes how the Maximize Capacitated Coverage problem handles demand: • Unlike Maximize Coverage, Maximize Capacitated Coverage doesn't require an impedance cutoff; however, when an impedance cutoff is specified, any demand point outside all the facilities' impedance cutoffs is not allocated. • An allocated demand point has all or none of its demand weight assigned to a facility; that is, demand isn't apportioned with this problem type. • If the total demand within the impedance cutoff of a facility is greater than the capacity of the facility, only the demand points that maximize total captured demand and minimize total weighted impedance are allocated. **Note:** You may notice an apparent inefficiency when a demand point is allocated to a facility that isn't the nearest solution facility. This may occur when demand points have varying weights and when the demand point in question is covered by more than one facility's impedance cutoff (or there are no impedance cutoffs at all). This kind of result indicates the nearest solution facility didn't have adequate capacity for the weighted demand, or the most efficient solution for the entire problem required one or more local inefficiencies. In either case, the solution is correct.

The basic steps to perform any type of network analysis in Network Analyst include the following:

1. Configuring the Network Analyst environment
2. Adding a network dataset to ArcMap
3. Creating the network analysis layer
4. Adding network analysis objects
5. Setting network analysis layer properties
6. Performing the analysis and displaying the results

These steps are presented in more detail in the GIS User Manual that has been prepared to show how to undertake location-allocation analysis using Network Analyst in ArcGIS.

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Secondary Education Enhancement Programme

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