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Title: Spatially targeting the distribution of agricultural input stockists in Malawi

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Keywords: Rural agro-dealer networks; Locational efficiency; Geographical Information Systems; Accessibility; Set Coverage Problem

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Abstract: Developing the rural agricultural input markets in sub-Saharan Africa can improve the current low productivity of smallholder farmers. Malawi has seen significant efforts in addressing the availability of agricultural inputs at village level in the last few years; for example, the improvement of rural agro-dealer networks. Nevertheless inputs are still difficult to obtain for many remote smallholder farmers. Spatial analysis can help in the expansion of input stockists, especially agro-dealer networks, by assessing the coverage of existing input outlets and deriving optimum locations for village-level input stockists.

We address three research questions. First, what is the locational efficiency of the current village-level stockists of inputs (Citizens Network for Foreign Affairs - Rural Agricultural Market Development Trust trained network of agro dealers and public sector)? Secondly, how many village-level stockists of markets are needed to reach 60% of the population in the central region of Malawi within one hour? Finally we address the potential spatial components of the sustainability of input stockists relating to the potential demand from smallholder farmers and the access to bulk supplies. The problem of finding the optimum location for village-level stockists of markets is addressed in two stages, using spatial analysis in conjunction with location-allocation models. First, the locational efficiency of the existing network of stockists of inputs is determined, followed by the establishment of a set of optimal sites for village-level stockists of inputs. A final step explores the viability of stockists and calculates the population surrounding the stockists taking into account competition from other sources of inputs and the accessibility of the selected stockists to potential wholesalers who are bulk distributors of farm inputs.

Our results show that locational efficiency can be assessed in terms of the differential access of households to resources and transport. Often, these differences are not considered in coverage problems and can have a large effect on the physical access to inputs. The results can be used to define which areas are inherently difficult to serve with agricultural inputs and could inform efforts to provide incentives to remote areas. Further implications for input policies in Malawi are that improvements in road infrastructure might not directly benefit the poorest farmers (if they are walking) but could serve to reduce the wholesale prices and therefore the retail price. In addition, the improvement in roads might increase the number of potential customers of any particular stockist, with economies of scale allowing the reduction of prices while ensuring a satisfactory profit margin for the stockist. The results of our models imply that Citizens Network for Foreign Affairs may need to

train stockists over a wider area to increase the access to inputs of those smallholder farmers with least resources.

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Editorial Board
Agricultural Systems

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Dear Editors

Please find attached a copy of our manuscript titled "Spatially optimising the distribution of agricultural input stockists in Malawi". In the paper we develop novel spatial analytical methodology to help improve the 'locational' efficiency agro-dealer networks and investigate the implications for policy. This work has not been submitted previously for publication and we feel that our combination of geographical science for agricultural production and marketing would be of interest to your readership.

The work is pertinent given the ongoing debate on the implementation of input subsidies in much of Sub-Saharan Africa and specifically within Malawi. The implications of our work for input policies in Malawi are that improvements in road infrastructure might not directly benefit the poorest farmers but could serve to reduce the wholesale prices and therefore the retail price. In addition, the improvement in roads might increase the number of potential customers of any particular stockist, which would improve profitability and feasibly lead to lower prices for all consumers. The results of our models imply that donors may need to invest in capacity building for many new stockists, especially if the target population includes those smallholder farmers with least resources who have no access to transport and are reliant on walking to access inputs.

Yours sincerely

Andrew Farrow

Revision Notes

Abstract: acronyms spelled out
Page 3 line 2, may need to train
P 5, l 14, IFDC spelled out (although the organisation is now known only by the acronym)
P 9, l 17, RUMARK were used as
P 12, l 2, intensity we developed
P 12, l 5, again searched for
P 14, l 4 para onwards - acronyms spelled out
P 15, l 4 and 5, speed superscripts fixed
P 16, l 22, "1 hour" changed to "one hour" (and elsewhere in the paper for numbers from 1 - 9).
Table 1 - codes changed to roadclass descriptions (needed for anyone wishing to replicate the analysis?)
Table 3, acronym spelled out
Figure captions - acronyms spelled out

References: UNESC – hyperlink to document changed since this was a deadlink

Research Highlights

- Heuristic for calculating the locational efficiency of agro-dealers developed
- Optimal sites for village-level input stockists and wholesalers determined
- Improvements in road infrastructure might not directly benefit the poorest farmers
- More stockists required to reach most remote small-holder farmers

Spatially targeting the distribution of agricultural input stockists in Malawi

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Abstract

Developing the rural agricultural input markets in sub-Saharan Africa can improve the current low productivity of smallholder farmers. Malawi has seen significant efforts in addressing the availability of agricultural inputs at village level in the last few years; for example, the improvement of rural agro-dealer networks. Nevertheless inputs are still difficult to obtain for many remote smallholder farmers. Spatial analysis can help in the expansion of input stockists, especially agro-dealer networks, by assessing the coverage of existing input outlets and deriving optimum locations for village-level input stockists.

We address three research questions. First, what is the locational efficiency of the current village-level stockists of inputs (Citizens Network for Foreign Affairs - Rural Agricultural Market Development Trust trained network of agro dealers and public sector)? Secondly, how many village-level stockists of markets are needed to reach 60% of the population in the central region of Malawi within one hour? Finally we address the potential spatial components of the sustainability of input stockists relating to the potential demand from smallholder farmers and the access to bulk supplies. The problem of finding the optimum location for village-level stockists of markets is addressed in two stages, using spatial analysis in conjunction with location-allocation models. First, the locational efficiency of the existing network of stockists of inputs is determined, followed by the establishment of a set of optimal sites for village-level stockists of inputs. A final step explores the viability of stockists and calculates the population surrounding the stockists taking into account competition from other sources of inputs and the accessibility of the selected stockists to potential wholesalers who are bulk distributors of farm inputs.

Our results show that locational efficiency can be assessed in terms of the differential access of households to resources and transport. Often, these differences are not considered in coverage problems and can have a large effect on the physical access to inputs. The results can be used to define which areas are inherently difficult to serve with agricultural inputs and could inform efforts to provide incentives to remote areas. Further implications for input policies in Malawi are that improvements in road infrastructure might not directly benefit the poorest farmers (if they are walking) but could serve to reduce the wholesale prices and therefore the retail price. In addition, the improvement in

roads might increase the number of potential customers of any particular stockist, with economies of scale allowing the reduction of prices while ensuring a satisfactory profit margin for the stockist. The results of our models imply that Citizens Network for Foreign Affairs may need to train stockists over a wider area to increase the access to inputs of those smallholder farmers with least resources.

Keywords: Rural agro-dealer networks, Locational efficiency, Geographical Information Systems, Accessibility, Set Coverage Problem

1 Introduction

1.1 Agricultural input use in sub-Saharan Africa

Evidence indicates that much of the rural population in developing countries cannot reach stockists of farm inputs because of poor geographical accessibility (Morris et al., 2007; Edmonds, 1998). Most farm input supply companies remain concentrated in urban areas or rural zones with large concentrations of commercial farmers (Kormawa et al., 2003). Therefore, millions of poor smallholder farmers in rural areas do not have access to affordable agricultural inputs, such as improved seeds, chemical fertilizers, and other agro-chemicals needed to help them raise their farm productivity. The poor development and weak performance of rural agricultural input markets explain to a large extent the current low productivity of smallholder farmers (Denning et al, 2009).

Farmers often travel great distances to access basic farm supplies and may often find the supplies unaffordable. This has made it difficult for small-scale farmers to increase their yield or incomes, leaving them stuck in poverty. Studies by Kherallah et al. (2000) and Kydd et al. (2004) revealed that, although there have been pockets of increased input use (e.g., some export crop sectors), the vast majority of Africa's smallholder farmers rarely use modern inputs. This is particularly so for farmers located in remote areas, where poor transport infrastructure increases input prices (Jacoby, 2000; Kelly et al., 2003; Kamara, 2004; Morris et al., 2007) and reduces output prices (Sperling, personal communication, 28th March 2011). Governments in sub-Saharan Africa (SSA) can play a very important role in promoting the expansion of input use by investing in the basic public goods that will stimulate farmers to intensify agricultural production, and the commercial sector to supply improved inputs (Gregory and Bumb, 2006). Among the important public goods to be invested in are rural infrastructure (roads, markets, electrification), basic education (particularly in rural areas), agricultural research and extension, and market information systems (Imperial College London et al., 2007). Until there is serious commitment to provide these basic public goods, large-scale government input subsidies, credit, or distribution programs are unlikely to have any lasting impact on agricultural productivity and diversity, rural incomes, national food and nutritional security, or poverty reduction.

1.2 The situation in Malawi

Malawi has seen significant efforts by donor funded projects working in collaboration with the Government of Malawi and the private sector to address the availability of agricultural inputs at village level in the last few years through the improvement of rural agro-dealer networks. These networks increase input availability by first improving the technical knowledge of inputs and managerial skills among rural traders and then reducing capital constraints through a system of guarantees that reduce the risk of supplying farm inputs on credit. Research has revealed that agro-dealer programs can effectively link input suppliers to rural markets and, as rural markets expand, farmer input search costs and prices should decline (Kelly et al., 2003). The Agricultural Development and Marketing Corporation (ADMARC) has been the primary organisation responsible for the marketing of smallholder inputs and outputs in Malawi (Chilowa, 1998). With the liberalisation of the economy, a number of alternative organisations have emerged within the agricultural sector. Establishment of agro-dealer networks in Malawi was initiated by theInternational Fertilizer Development Center (IFDC) in the 1990s.

Malawi has also benefited from the recently launched Alliance for a Green Revolution in Africa (AGRA) Agro-dealer Development Program (ADP), which aims to provide training, capital and credit needed by small retailers in rural communities to become certified agro-dealers. In Malawi the ADP has been led by the Citizens Network for Foreign Affairs - Rural Agricultural Market Development Trust (CNFA-RUMARK). The ADP has sought to strengthen the network of agro-dealers and increase the number of dealers from 160 in 2007 to over 600 (AGRA, 2007). Nevertheless, unpredictable government policies on fertiliser subsidies mean that public sector retailers (ADMARC and the Smallholder Farmer' Fertiliser Revolving Fund of Malawi SFFRFM) continue to be major suppliers of fertilisers to farmers.

Poor physical accessibility to both private and public sector retailers increases costs for farmers (Kelly et al., 2010; Imperial College London et al., 2007). To improve the efficiency of subsidies and maximize the benefits from expansion of the agro-dealer network in Malawi it is necessary to pinpoint underserved areas and identify optimal sites for locating new agro-dealers (Dorward et al., 2008). The current and future agro-dealer network development programmes can benefit from location modelling to derive optimum locations for these village level input stockists.

1.3 Location modelling for rural development

Rahman and Smith (2000) propose that one of the tools for location analysis in planning for regional development is quantitative location-allocation modelling. This provides a framework for investigating service accessibility problems, analysing previous locational decisions and generating alternatives to suggest more efficient service systems. Location-allocation models optimise locational decisions based on one or more objectives such as cost minimization, or accessibility maximization for the efficient allocation of resources. Location models/problems have been studied extensively since the 1960s, in the operational research, management science, industrial engineering, economic geography and spatial planning literatures (Teixeira and Antunes, 2006). Many studies have used this concept for public health facilities but little has been done in solving problems of stockists of inputs in the agriculture context. There is therefore an opportunity to use locational modelling to determine the physical accessibility of the population in maize growing areas to existing trained stockists of agro-inputs, and to help provide recommendations for the locations of new stockists or for capacity building for non-trained stockists.

This study focuses on addressing three main research questions:

1. What percentage of the maize growing population in the central region of Malawi is currently within one hour of a CNFA-RUMARK trained agro-dealer or public sector retailer?
2. How many additional agricultural input retailers are needed to reach 60% of the maize growing population in the central region of Malawi within one hour and where should they be located?
3. How viable is the input retailer considering the surrounding population, competition from other dealers and accessibility to wholesalers?

Section 2 describes the data available for this study and the conceptual framework used to develop methods to analyse farmers’ access to existing CNFA and public sector retailers and to explore the locations of alternative and new stockists. The results of different transport scenarios are described in Section 3, and the paper concludes in Section 4 with a discussion of how the results can be used in practice by CNFA and other facilitators of agro-dealer networks in Malawi, and further research required.

2 Methods and materials

The problem of finding the optimum location for agro-dealers is addressed in two stages using spatial analysis in conjunction with location-allocation models (LAM). First, the 'locational efficiency' of the existing network of stockists of inputs (agro dealers) is determined, followed by the establishment of a set of optimal sites for village level input stockists. A final step explores the viability of stockists and calculates the surrounding population taking into account the competition from other stockists, and accessibility of the agro-dealers to potential wholesalers who are bulk distributors of farm inputs.

2.1 Determining locational efficiency

For this paper locational efficiency is the relationship between the resources allocated to the agricultural inputs system in terms of effective retail outlets, and the outputs of the system, i.e. the quality of the service of those outlets to the farming population. Village-level stockists of inputs are considered as central facilities (Hodgart, 1978) to which people must travel to receive the service, or from which a service is provided to the whole community of interest. We take the position that the closer (measured in terms of time) the facilities are to the users, the less costs for the users and an increased likelihood in users availing themselves of the services. The concept of acceptable proximity, which involves presetting a maximal value for either distance or travel time, is employed (Church and ReVelle, 1974). We use a value of one hour as our maximal one-way travel time to represent an acceptable proximity/cost for farmers for obtaining inputs, and 60% of the population in maize-growing areas as the coverage objective for CNFA-RUMARK.

Some Geographical Information Systems (GIS) have evolved to include embedded location models and many provide the opportunity to integrate location models within a map-based user interface (Church, 2002). Many location problems using GIS are undertaken in a vector data environment (Church, 2002), where population or demand centres are nodes in a network connected by roads of differing speeds (e.g., Møller-Jensen and Kofie, 2001; Spaulding and Cromley, 2007). In the case of Malawi, we are primarily concerned with a rural population that may not be always connected by roads, or where spatial datasets of rural or feeder roads have not been collected. This implies a 'raster' or grid data modelling environment. Locational efficiency in this study was therefore determined using the Accessibility Analyst modelling tool (Farrow and Nelson, 2001) for the ArcView v3.2 GIS software (ESRI Inc, 2000) based on the COSTDISTANCE algorithm. Target locations are chosen and a 'friction surface' is created that represents the time required to cross multiple raster cells. In the model, location data of the agro-dealers trained by CNFA-RUMARK were used as the target coverage; in addition, ADMARC and SFFRFM outlets were included to assess the competition from these alternative sources of farm inputs.

This study considers three scenarios that modify the friction surface. These scenarios represent the different transportation options for households of different wealth classes

(Riverson and Carapetis, 1991; Sieber, 1998; Benson, 2002) or scales of operation: (i) motorised transport, (ii) bicycle, and (iii) walking.

2.2 Optimising the location of village-level stockists of inputs

Where underserved populations are discovered we use location models to provide recommendations for the ‘optimum’ location of new stockists or to identify existing agro-dealers who have not been trained by CNFA. Our version of what is known as the ‘set covering problem’ (Church and ReVelle, 1974) attempts to select the minimum number of new or untrained stockists in order to meet the threshold population (60%) within the stated range (one hour).

There are few tools for solving the set coverage problem in a raster modelling environment. Our approach therefore used existing raster accessibility algorithms within a custom-made heuristic for determining near optimal locations of stockists. Having assessed the coverage of existing CNFA and public sector stockists (ADMARC and SFFRFM) for those scenarios where more than 40% of the target population is uncovered, we select from a set of new locations until at least 60% of the population is serviced within the one-hour range.

The problem formulation follows Klastorin (1979, pp. 109-110) whereby:

There is a set J = {1, 2,. . . . , n} of population centres (grid cells), each with a known location and demand (population) p_j. In addition, there is a set I = {1, 2, . . . , m} of CNFA-trained agricultural input stockists and public sector retailers, and a set G = {1, 2, . . . , l} of untrained, non-CNFA-trained agro-dealers or completely new locations (we use the location of dispensaries and clinics as potential new locations). A maximum allowable range (R) is specified at one hour. If the minimum number of stockists necessary to serve all population centres within the given range exceeds the allotted number (m), additional facilities ($1_{\text{to}}\, l$) can be allowed. Coverage is calculated using the same COSTDISTANCE algorithm and the friction surfaces developed for the three transport scenarios.

Having already determined the coverage for set I we need to select the minimum number of stockists from set G which allow the 60% coverage of the population within one hour. We choose each stockist in set G, calculate the coverage and record the population within the one-hour range and select the stockist with the greatest population coverage. We then recalculate the total population coverage and, if our objective is not achieved, we increase the number of selected stockists from set G. After this first iteration, the search for an optimal solution implies taking into consideration all combinations of stockists from set G. The number of combinations is defined by $l!/(l\text{-i})!$, where l is the total number of stockists and i is the number of stockists considered in a particular iteration. For large numbers of stockists in set G this is computationally intensive; for instance with 100 stockists in set G finding the greatest population coverage for 3 stockists gives 100*99*98 = 100!/97! = 970,200 possible combinations.

To limit the computational intensity we developed a ‘greedy add’ heuristic (Park, 1989; Schilling et al., 1993; ReVelle and Eiselt, 2005; de Smith et al., 2007). Thus in the second iteration we excluded the population already covered in the first iteration and again searched for the stockist with the greatest population coverage. We followed this process until the covered population within one hour is 60%, at which point the model stops (Farrow, 2010).

2.3 Viability of agro-dealers

The viability of agro-dealers is likely to have an impact on the sustainable expansion in numbers of outlets and consequently the geographic coverage of input supply in Malawi (Kelly et al., 2010). Financial viability is determined by the profit per unit of input, and the volume of sales of agricultural inputs which in turn is linked to the potential surrounding population. We thus consider two geographical components of viability for agro-dealers; firstly the potential demand in terms of the population within one hour, and the competition for that demand from other retailers of agricultural inputs, and secondly the accessibility of the retailers, whether in the private or public sector to bulk supplies of inputs.

One of the results of the accessibility analysis is a catchment area for each outlet, i.e. those places that are closer (in time) to a particular outlet than any other. For each transport scenario we calculate the population within one hour for each outlet’s allocation areas, and calculate summary statistics for all stockists. There are no figures for what represents a break-even demand for input stockists in Malawi, but we use a cumulative population of 5000 as a threshold based on population thresholds in other contexts (e.g. Thilmany et al., 2005; Wanmali, 1992) and viable trading centre size in similar contexts (Mbonile, 1994). Where more than one outlet is located in the same location we share the population amongst those outlets.

For access to bulk suppliers of inputs we repeated the accessibility analysis but assume that there are five wholesale distributors of farm inputs who supply the local level stockists in central region located in Lilongwe, Dedza, Mchinji, Kasungu and Dowa. These are large market centres and have existing market infrastructure. This is an exploratory analysis to determine the number and percentage of the stockists that are themselves within one or two hours of a wholesaler. The friction grid used is the same as for the motorised scenario, given that stockists are likely to need vehicles to transport inputs in bulk.

2.4 Spatial Data

The Malawi Central region has been chosen as the study area because it is agriculturally the most important region in Malawi, contributing most to the national food crop production.

The dataset of outlet locations was provided by CNFA and includes 69 agro-dealers trained by CNFA-RUMARK in 2007. The other input dealer dataset was compiled by IFDC in 2004 and contains 125 ADMARC and 9 SFFRFM outlets, and 347 other private sector retail outlets (Agora 4, Agri-Input Suppliers Association of Malawi 229, Agricultural Trading Company 2, Chipiku Stores 20, Farmers World 42, Kulima Gold 14, McConnell & Co. 18, Metro Shop 1, National Smallholder's Farmers Association of Malawi 11, OptChem 1, Rab Processors 4, Yara Malawi Ltd 1). All of the CNFA trained agro-dealers in our dataset are located in the Central Region of Malawi, but 17 of the ADMARC/SFFRFM outlets and 33 of the other private sector retailers were located in the districts of Balaka, Mangochi and Mwanza in Southern region, and in Mzimba district in Northern region. There were a further 57 CNFA trained agro-dealers, and one ADMARC/SFFRFM stockist in Central region but these had no geographic coordinates and were thus excluded from the analysis. Between 2004 and 2007 38 of the AISAM agro-dealer network had moved to CNFA and were excluded from the analysis. The dataset of health facilities, used as potential new locations for stockists, contains 246 dispensaries and health centres in Central region (MoHP, 1998).

The spatial resolution of the modelling is a 30 arc-second raster cell (approximately 1 km x 1 km). The values assigned to cells are therefore the time required to cross the cell in a cardinal direction (East, South, West or North). Movement in diagonal directions are calculated automatically in the COSTDISTANCE calculations. Spatial data have been projected to a customised Lambert Azimuthal Equal Area projection, where the central meridian and latitude of origin are appropriate for Malawi.

The most important dataset is the road network, which should contain information on the road surface or road quality. We use the road network from the government of Malawi (UNESC, 2006), which has seven road quality classes; the most important roads (roadclass M, S and T) allow speeds of up to 50km/h, while other roads allow speeds of up to 30km/h . These speeds are reduced in the bicycle and walking scenarios (Table 1).

Table 1 somewhere here

Land use classes of the Malawi Land Use map (MoA/UNDP/FAO, 1992) are used to estimate the times needed to cross cells of the grid where no roads are present. For the motorised scenario we assume that vehicles are able to cross a cell using tracks that are not captured in the road database, and that the density of these tracks is higher in areas that are cultivated and lower for other types of land cover. Similarly for the bicycle and walking scenario we assume that paths are more common in cultivated areas rather than forests or marshes.

Effects of slope on travel time are also included by using slope grids derived from the 90 m SRTM (Reuter et al., 2007) digital elevation model (DEM). The slope gradients are classified to apply slope factors to the cost grid derived from land use classes and roads. These factors multiply the time required to cross a cell and are applied constantly (Farrow and Nelson, 2001). We follow Nelson (2008) in the calculation of slope factors but apply more conservative values since we assume that paths and roads are constructed to minimise slope (via switchbacks for example) rather than use the maximum slope which is derived from the terrain model.

Population data are used in the analysis of locational efficiency, as well as in the modelling of optimum locations for new stockists. The source of the population data is Landscan2006 (Dobson et al., 2000), which has a resolution of approximately 1 km. The target population is modified so as to include only the rural population in maize-growing areas, as more than 90% of the subsidy fertilizer is used on maize. Information on maize growing areas (A1, A12, A17-A9 classes) is available from the land use map of Malawi (MoA/UNDP/FAO, 1992) and was used as a mask for the population data, with areas outside maize-growing areas excluded. It is unlikely that these land uses have changed considerably since 1992.

We only consider the population within the central region of Malawi and use the level 5 boundary data from USAID/FEWS (1996) as a further restriction on the target population.

3 Results

3.1 Locational efficiency of existing CNFA stockists

The areas within one hour of existing stockists in central region are greatest for the motorised transport scenario and reduce substantially for the bicycle and walking scenarios (Figure 1). The total population within the central region maize growing area is 3,756,566. For the motorised transport scenario the population within one hour of the CNFA certified stockists and ADMARC/SFFRFM outlets is 3,705,493, which is 98% of the total population. For the bicycle scenario the coverage is 3,252,666, equivalent to 87% of the population. Meanwhile, for the walking scenario, existing CNFA and government stockists are within one hour of only 1,811,994 people (48% of the population). These results imply that extra stockists are required if the poor rural population without access to transport is to be within one hour of agro-input stockists.

Figure 1 somewhere here

3.2 Optimisation of location of new stockists

The optimisation of the location of new stockists was necessary for the walking transport scenario. To reach the 60% threshold we needed to select 48 new agro-dealers. These were drawn from the candidates of non-CNFA trained stockists and new locations represented by health facilities. The first stockists selected during the optimisation model added the most population, with subsequent iterations of the model adding less and less – this is the essence of the greedy add heuristic. After approximately 20 iterations the contribution of each new stockist did not differ greatly from the previous one, nevertheless the model helped in the choice of these 48 stockists from the 593 candidate locations or agro-dealers.

Figure 2 somewhere here

Figure 2 shows the location of the stockists that would have to be added to cover the population thresholds of 60% for the walking scenario. The area where new stockists can make the most difference is to the east of Lilongwe.

3.3 Viability of stockists: Population demand and access to wholesalers

A bigger percentage of outlets have an exclusive population of greater than 25,000 people in the motorised scenario than either the bicycle or walking scenarios. The differences between the motorised and bicycle scenarios are, however, limited (Table 2). Adding extra outlets in the case of the walking scenario improves slightly the potential demand for each outlet. This is because almost all of the new outlets have a catchment population greater than our 5,000 person threshold within one hour.

Table 2 somewhere here

Access to inputs in bulk is another important consideration for all stockists. Table 3 gives the percentage of the existing and new stockists or locations that are within one or two hours of Lilongwe, Dedza, Mchinji, Dowa and Kasungu towns. For the walking scenario we also consider the new locations for stockists required to reach the threshold of 60% coverage. These results show that if a two-hour range is considered (Figure 3) then most of the CNFA and government stockists are within easy reach of suppliers; while if the stricter range is applied, then at best only half of the stockists would be viable. The new locations follow a similar pattern although a slightly higher percentage of these locations are within two hours of a stockist.

Table 3 somewhere here

Figure 3 somewhere here

4 Discussion and Conclusions

The analysis conducted in this study has shown that locational efficiency can be used to assess the impact of differential access to resources and transport; this is an improvement on previous analyses of access to agro-dealers in Malawi (e.g. Benson, 2002). Often, these differences at the household level are not considered in coverage problems and can have a very large effect on the physical access to inputs.

The method described here is novel because these algorithms have not been previously developed for raster GIS environments (cf Huang et al., 2006). The algorithm itself has been made available, with the aim of making this modelling easier and to encourage improvements by other modellers. We have shown above that the ‘greedy add’ heuristic reduces dramatically the number of computations necessary to provide an adequate solution, thus the time required to calculate the set of ‘optimal’ locations. There is a trade-off however between the ‘satisfactory’ result and the optimal result that could be produced using alternative methods such as simulated annealing or genetic algorithms. For this particular application we feel that a quick result is more appropriate to show the utility of location modelling for this coverage problem, although further research comparing methods would be beneficial.

Different outlets will be more or less attractive based on the prices of inputs, and the range of products available (e.g. the mixture of nutrients for specific crops, or the size of the packs) (Imperial College London et al., 2007), as well as other factors such as whether there are different reasons to visit the location (such as towns for purchasing other products, administrative centres, medical visits etc). The attractiveness of the different outlets has not been incorporated in this analysis due to a lack of data and limitations of the modelling framework but should be considered in further research (e.g. Suzuki and Hodgson, 2005 or Drezner et al, 2002).

The availability of agricultural inputs at different stockists in Malawi is influenced by the subsidies that are available in any particular season. The subsidy policy has an impact not only on the price that farmers will pay, but also which types of outlets receive subsidised inputs or which can process vouchers. Given the dynamic nature of the subsidy policies further research should add to the transport scenarios and consider policy scenarios which favour different combinations of large and small and different kinds of stockists. A specific component of input subsidies and a factor which could affect the attractiveness of stockists is an additional premium for more remote areas (Kelly et al, 2010), which has been implemented (albeit inconsistently) in Malawi between 2007 and 2010. However , this premium may be used to balance the effects of higher prices caused by transporting bulk supplies to remote locations and might not directly influence the purchaser (Imperial College London et al., 2007). Indeed the assessment of ‘locational efficiency’ that we have demonstrated in this paper could inform the process of choosing ‘remote’ areas.

The viability of individual stockists has been assessed in terms of both the demand as well as the potential supply issues. The potential demand in terms of population reduces significantly for the walking scenario. Even assuming that all purchasers make their journey by transport, many existing stockists manage to survive with a population threshold below 5,000. This suggests that stockists in new locations - which tend to have more than 5,000 people within the one-hour range – would be viable, assuming that the population is equally able to afford inputs. We also consider the supply-side feasibility of obtaining inputs in bulk for the locations of the new stockists. The analysis shows that new locations are no more remote than existing stockists. Better data on actual wholesale distributors would be required for a more in-depth study of the viability of stockists, as well as the incorporation of issues such as transport costs.

All of the locations selected by the heuristic were new locations rather than existing input suppliers. Setting up new agro-dealers will entail extra costs, either through the construction of new premises or investment by CNFA in capacity building for retailers who do not presently stock agricultural inputs. An alternative strategy would be to invest in mobile stockists that follow scheduled routes in order to reach these more remote areas, without requiring a permanent presence (e.g., Foti et al., 2007) and that may improve the viability of stockists in remote areas.

The implications for input policies in Malawi are that improvements in road infrastructure might not directly benefit the poorest farmers (if they are walking) (cf Edmonds, 1998) but could serve to reduce the wholesale prices and therefore the retail price. In addition, the improvement in roads might increase the number of potential customers of any particular stockist, with economies of scale allowing the reduction of prices while ensuring a satisfactory profit margin for the stockist. Nevertheless the participation of a diversity of suppliers of agricultural inputs, which has been greatly influenced by subsidy policies, is likely to have a bigger impact on the access of remote smallholder producers to inputs. We have shown how the locational efficiency of input retailers can be assessed *a priori* and can be used to inform policy-making in a timely manner.

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Table 1. Time required to cross a 30 arc second grid cell according to theme and class, for each transport scenario.

Description	Time (seconds)		
	Motorised	Bicycle	Walking
Roads			
Main, Secondary and Tertiary	72	240	720
District and Other roads	120	240	720
Land Use			
Lakes	50,000	50,000	50,000
Urban areas	240	240	720
Forest plantations	2,000	2,000	2,000
Wetland cultivation	480	480	720
Dimba cultivation	480	480	720
Grasslands	480	480	720
Marshes	2,000	2,000	2,000
Cultivation	480	480	720
Rock outcrops	2,000	2,000	2,000
Woodlands	2,000	2,000	2,000
Slope	Multiplication factor		
0°-10°	1		
10°-30°	2		
30°-90°	3		

Table 2. Exclusive population within one hour of outlets.

Scenario		Exclusive population within one hour			
		> 25,000	> 10,000	> 5,000	> 1,000
Motorised (n=202)	% of stockists	25	61	79	90
Bicycle (n=202)		21	60	78	90
Walking (n=202)		4	36	64	88
Optimal (all) (n=250)		4	37	69	90
Optimal (new) (n=48)		2	54	98	100

Table 3. Percentage of stockists within one and two hours of wholesalers (delivery using vehicular transport).

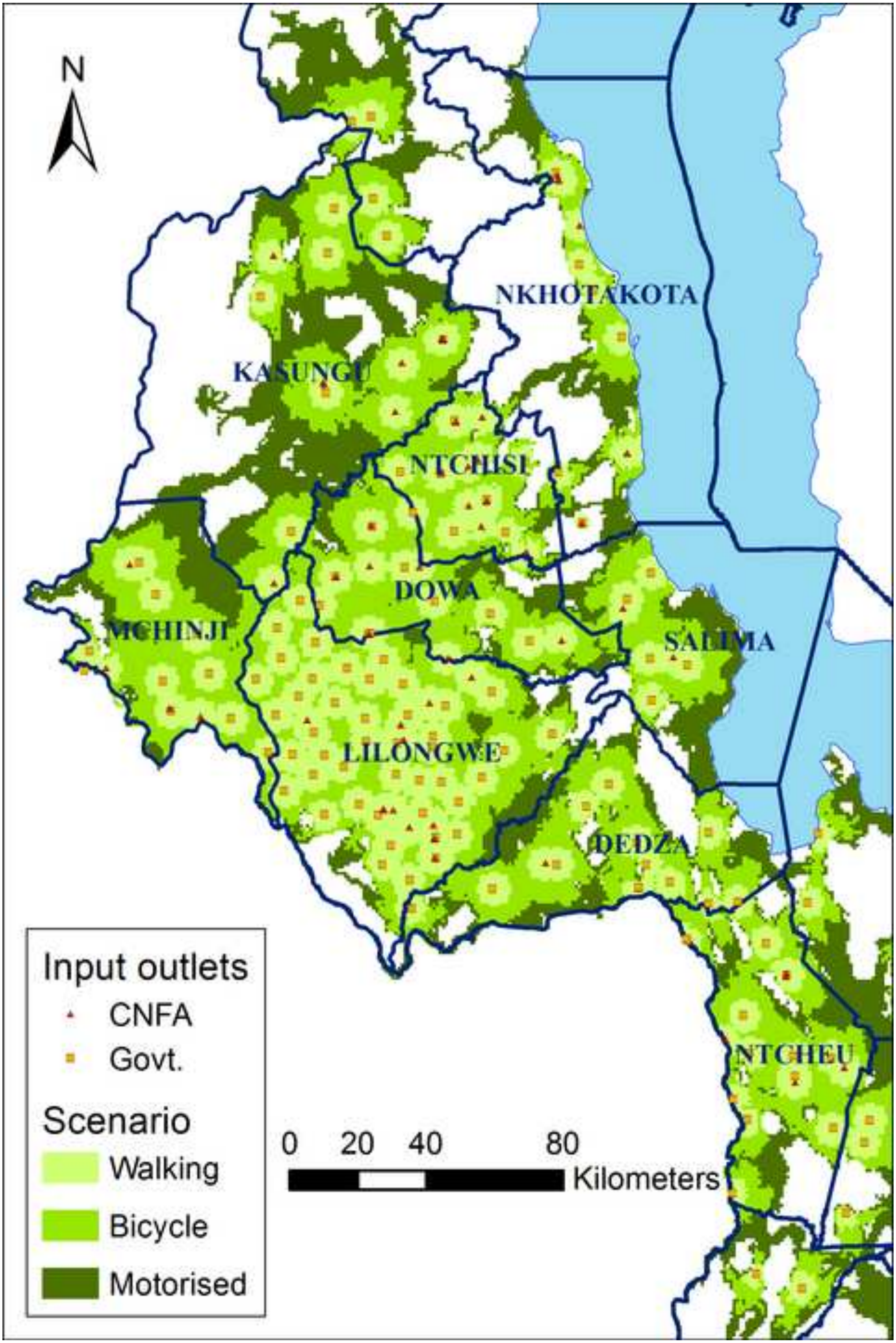
Outlets	Stockists within times of wholesalers (%)	
	One hour	Two hours
Citizens Network for Foreign Affairs and government stockists (Agricultural Development and Marketing Corporation and Smallholder Farmer’ Fertiliser Revolving Fund of Malawi) (n = 202)	46	86
Optimal (new) (n = 48)	44	92

Figure Captions

Figure 1. Areas within one hour of Citizens Network for Foreign Affairs and government (Agricultural Development and Marketing Corporation and Smallholder Farmer' Fertiliser Revolving Fund of Malawi) stockists in the central region of Malawi, according to different transport scenarios.

Figure 2. Areas within one hour of Citizens Network for Foreign Affairs and government (Agricultural Development and Marketing Corporation and Smallholder Farmer' Fertiliser Revolving Fund of Malawi) stockists, and new stockists in the central region of Malawi, according to the walking scenario.

Figure 3. Citizens Network for Foreign Affairs and government (Agricultural Development and Marketing Corporation and Smallholder Farmer' Fertiliser Revolving Fund of Malawi) stockists, and new stockist locations in walking scenario in the central region of Malawi within one or two hours of potential wholesalers.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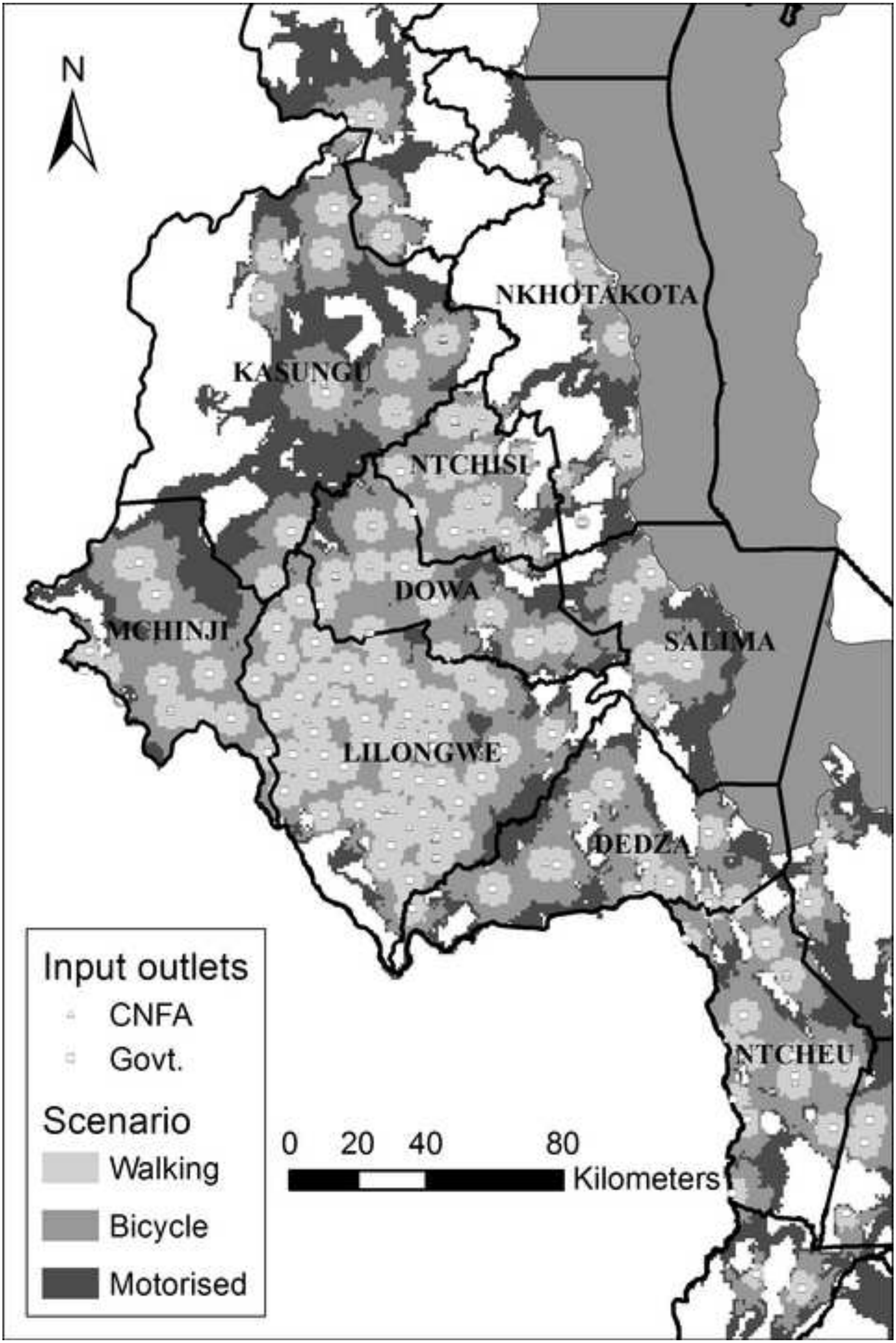
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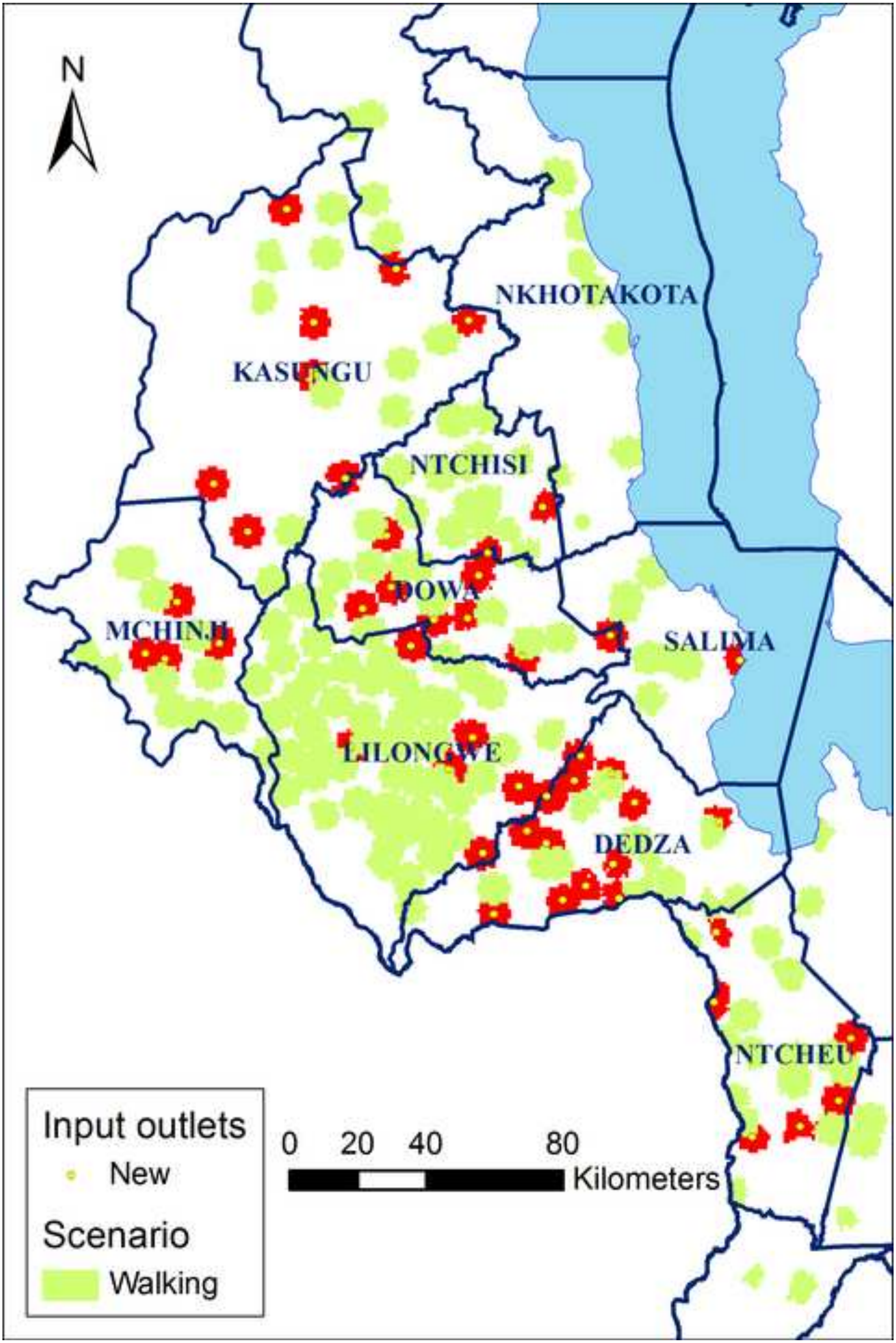

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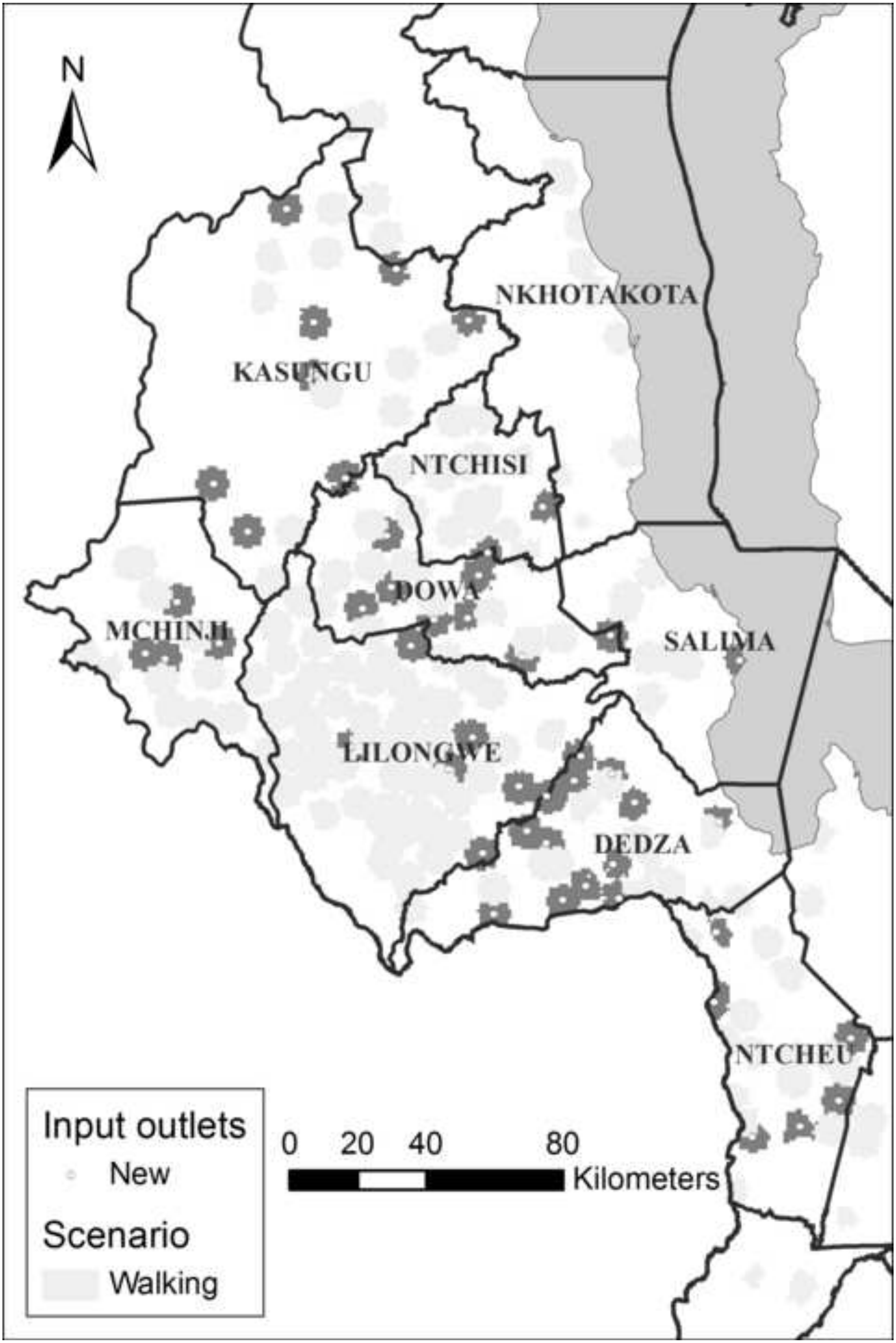

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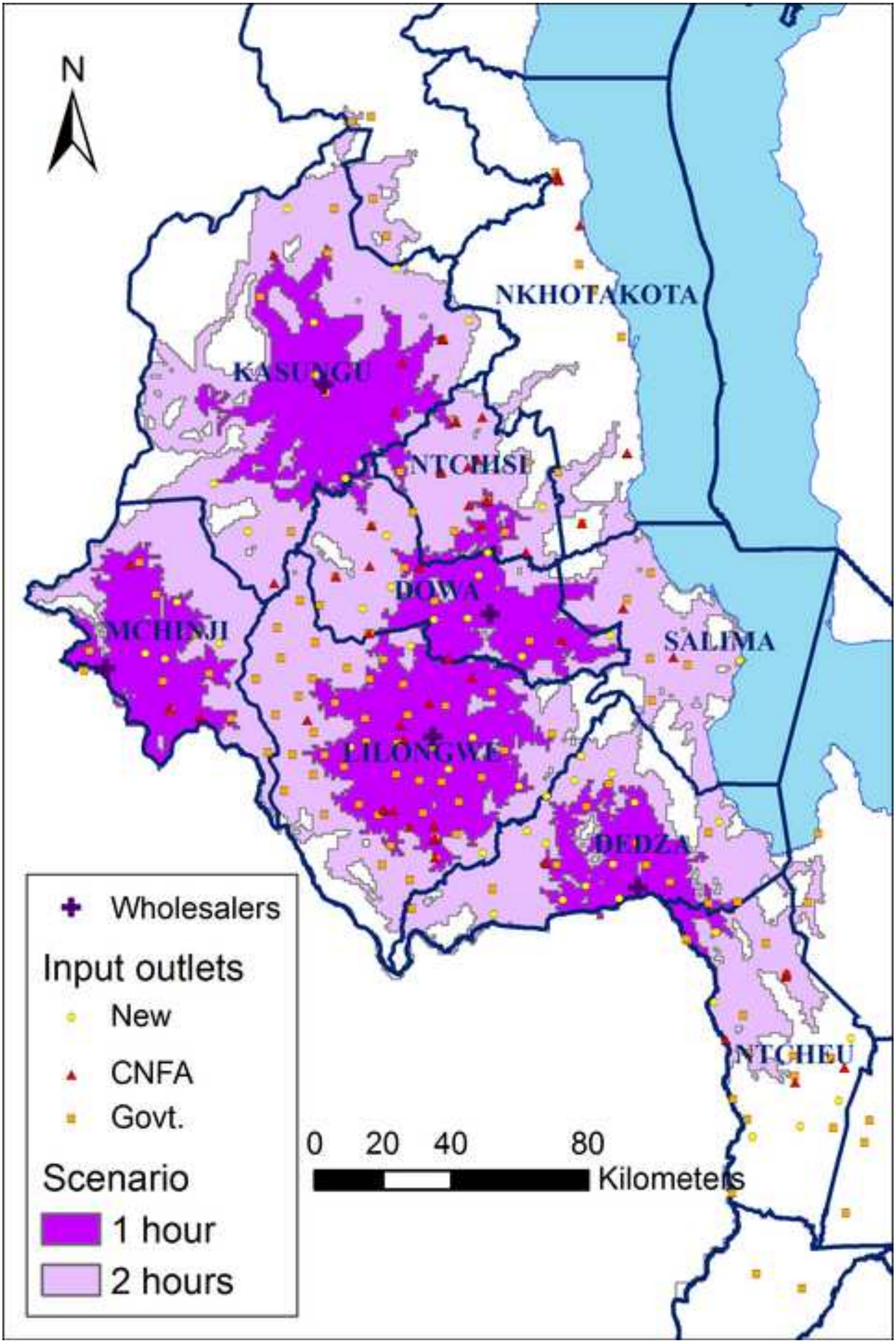
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