

1 **Spatial accessibility modelling of agricultural extension services among rural** 2 **smallholder macadamia farmers in Neno district, Malawi**

3 **Abstract**

4 Agricultural extension and rural education are vital for poverty reduction and food
5 security. However, rural smallholder farmers' access to agricultural extension services (AES) is
6 challenging in Malawi. This study investigates the travel times required by Neno Smallholder
7 Macadamia Cooperative (NESMAC) members to access AES in the Neno district of Malawi. We
8 use a cost-friction algorithm coupled with key informant interviews to calculate travel time by
9 integrating NESMAC's central meeting locations (NCMLs) with spatial databases of road
10 networks, elevation, and land use. The analysis considers four travel scenarios: (i) walking only
11 (pessimistic), (ii) bicycle only (pragmatic), (iii) motorcycle only (optimistic), and (iv) vehicle only
12 (most optimistic). Our findings reveal the presence of travel time inequalities among NESMAC
13 members. The travel time to reach NCMLs ranges from 0.1 to 789 minutes for the walking scenario,
14 0.1 to 251 minutes for bicycle only scenario, and 0.1 to 57 minutes for the motorized scenarios.
15 We also uncover that the catchment area for reaching NCMLs within a 1- hour travel time increases
16 by 19.5% (6 villages in Neno and 10 in Lisungwi) when using bicycles and 100% with motorized
17 transportation, in comparison to 3.7% when walking. Hence, providing bicycles to members can
18 substantially enhance NESMAC's maximum coverage potential. Moreover, providing NESMAC
19 extension staff with reliable motorcycles can facilitate more farmer training and farm visits. This
20 is in contrast to the current practice where farmers have to gather at NCMLs. Based on our findings,
21 we recommend prioritizing road development, providing financial support to NESMAC to procure
22 and repair their motorcycles, and promoting targeted mass media initiatives focusing on
23 macadamia management and marketing to increase NESMAC coverage with support from the
24 Malawi Macadamia Association (MMA).

25 **Keywords:** *Agriculture extension services, Accessibility, NESMAC, Smallholder farmers, Travel*
26 *time.*

27 **1. Introduction**

28 Malawi's smallholder farmers face several challenges in their efforts to boost agricultural
29 productivity. Major challenges include a lack of information literacy, an overreliance on rainfed
30 agriculture, and a low adaptive capacity to climate change (Bhagwat, 2022; Bruce & Costa, 2019;
31 Rahman et al., 2023). Agricultural extension services (AES) is critical to addressing these
32 challenges. The FAO defines agricultural extension as a "transformative process that equips
33 farmers with the necessary tools to enhance their livelihoods and overall well-being" (FAO,
34 2022b). Consequently, AES can facilitate technology transfer, improve farmers' understanding of
35 good agricultural practices, support problem-solving, and enable farmers to access markets for their
36 produce (Feder et al., 2011; Bruce & Costa, 2019).

37 The Department of Agricultural Extension Services (DAES) in Malawi has taken steps
38 toward reforming extension service policies. These reforms aim to support farmers in gaining
39 access to the necessary information, skills, and knowledge to increase agricultural productivity in
40 light of climate change and land degradation (Agunga & Zeleza Manda, 2014; Maertens et al.,
41 2021). For example, the Malawi government has implemented the "pluralistic and demand-driven"
42 extension policy (Government of Malawi, 2000). This policy is regarded as the country's most
43 progressive agricultural extension strategy. The policy emphasizes decentralized, demand-driven
44 services and promotes the participation of multiple service providers to ensure that farmers have
45 access to high-quality extension services. As a result, the involvement of non-government actors
46 in delivering AES has increased over time (Chanza et al., 2023; Masangano & Mthinda, 2012).
47 Malawi currently has over 150 agricultural-related organizations and programmes that prioritize
48 the provision of AES (Lee et al., 2023).

49 Despite the proliferation of AES providers, studies have consistently revealed deficiencies
50 in the effective coverage and delivery of these services (Lee et al., 2023; Mkisi, 2011; Ragasa et

51 al., 2017). Subsequently, Malawi has experienced a state of agricultural productivity stagnation
52 and widespread food insecurity, especially among smallholders (Kevan et al., 2021). The primary
53 challenge identified is the shortage of extension workers, with an average ratio of one extension
54 worker for every 3000 farmers, far below the recommended ratio of 1 to 750 (Khaila et al., 2015).
55 While, in some areas, extension workers are completely absent (Ragasa, 2018).

56 Access to AES varies across districts and Extension Planning Areas (EPAs). This is
57 especially evident in districts like Chitipa and Neno, where poor road networks and mountainous
58 terrains make it difficult for extension workers to reach farmers (Lee et al., 2023; Ngwira &
59 Majawa, 2018). Hence, farmers in such remote areas lack the necessary extension training and
60 support, which may hinder the adoption of good agricultural practices. Further, the advice provided
61 by most extension workers focuses primarily on staple and cash crops, ignoring the support
62 required for emerging crops like macadamia (Zuza et al., 2023) and quinoa (Maliro et al., 2017).
63 This neglect creates a significant barrier for farmers growing these crops because they fear
64 receiving inadequate assistance that is not tailored to their needs.

65 Macadamia (*M. integrifolia*), known as the ‘queen of nuts’ has gained popularity globally
66 due to its high nutritional (Bouarakia et al., 2023a; Hu et al., 2022) and export value (Oloffson et
67 al., 2021). Over the past decade, global macadamia production has more than doubled, with
68 established growing regions continuing to expand plantings (Bringhenti et al., 2023). Macadamia
69 nuts account for only 2% of the global tree nut production, with Malawi producing 3% (\geq 2000
70 metric tonnes of kernel) of the world's total macadamia nut production (Bouarakia et al., 2023b).
71 The crop is an important contributor to Malawi's food security, income generation, and export
72 diversification (Parshotam, 2018; Zuza et al., 2023). Thus, macadamia production in the country
73 has the potential to alleviate poverty, promote health, and enhance food security among the
74 producers.

75 Nevertheless, macadamia nut yields among smallholder farmers in Malawi are generally
76 lower ($\leq 200 \text{ kg ha}^{-1}$) than the optimal (1500 kg ha^{-1}) (Evans, 2021). This is attributed to the scarcity
77 of AES, particularly the absence of government extension staff and macadamia experts (Zuza et
78 al., 2021a). Due to a lack of funding, the situation has worsened as previous projects have phased
79 out (Parshotam, 2018; Evans, 2021). Thus, macadamia production has become unsustainable,
80 leaving many smallholders unable to fully reap the long-term benefits of the crop (Evans, 2021;
81 Zuza et al., 2021a). For macadamia production to remain viable, providing smallholder farmers
82 with the necessary AES and technical support is essential.

83 Currently, cooperative extension services offer a more feasible option for the provision of
84 macadamia management training. NESMAC is an example of a cooperative that benefits from
85 skilled extension workers who provide training to their members. Nonetheless, NESMAC is a
86 farmer-owned cooperative with limited funding, and this has lessened their extension contact with
87 farmers. Consequently, farmers meet their extension workers at prearranged times and locations,
88 typically in centralized spots. Despite this arrangement, several farmers has expressed concern
89 regarding the extensive distances they must travel to access the central meeting locations (Evans,
90 2020). This situation has led to low training attendance, coupled and exhaustion, which becomes a
91 hindrance. This is especially important in hard-to-reach rural areas that lack motorized travel
92 alternatives. To our knowledge, there is a paucity of studies focusing on evaluating the travel times
93 required for smallholders to access extension services in Malawi and Sub-Saharan Africa at large.
94 Hence, our study seeks to assess the travel times required for NESMAC members to access
95 extension services in Neno district of Malawi.

96 Accordingly, our study addresses this knowledge gap to help improve the accessibility of
97 AES for NESMAC members. We examine the travel times required for these farmers to reach
98 NCMLs (central EPA) to receive training and extension support. Our study contributes to current

99 knowledge by providing empirical evidence regarding the challenges faced by farmers in remote
100 areas due to limited access to AES. We identify specific barriers that prevent farmers from fully
101 benefiting from extension programs, including geographical constraints, inadequate road and
102 transportation infrastructure, and a scarcity of extension workers. These findings shed light on the
103 importance of targeted interventions and policy initiatives to promote more equitable and efficient
104 AES. Such measures can foster sustainable agricultural development and enhance the livelihoods
105 of farming communities in underserved areas.

106 **2. Materials and methods**

107 **2.1. Study area**

108 In this study, we evaluate the accessibility of NESMAC extension services in Neno district
109 (Figure 1). The district is located in southern region of Malawi (situated at 15° 19' S latitude and
110 34° 46' E longitude) and shares borders with Moçambique to the west and is surrounded by Ntcheu,
111 Balaka, Zomba, Blantyre, Chikwawa, and Mwanza districts to the north, northeast, east, south, and
112 southwest, respectively (Kavwenje et al., 2022). The district is renowned for its thriving
113 agricultural activities. Among the prominent crops cultivated are cotton, potatoes, and various fruit
114 species, including citrus and macadamia nuts. Regarding agricultural administration, the district is
115 under the Blantyre Agricultural Development Division and is divided into two EPAs; Neno and
116 Lisungwi, comprising 13 and 17 extension sections, respectively (Government of Malawi, 2022).
117 Despite the vast land area (155,000 ha), Neno district is sparsely populated (Figure 2), with an
118 approximate count of 161,985 individuals spread across 131 gazetted villages (McCarthy et al.,
119 2023).

120 **Figure 1: Geographic location of Neno district.** Source: Authors.

121 The landscape in Neno district varies, with hilly areas reaching over 1600 meters above sea
122 level (m.a.s.l.) in the Kirk range and flatter areas in the Shire Valley ranging from 200 – 1000
123 m.a.s.l. (Figure 2), creating diverse agroecological conditions. Weather patterns also differ in the
124 district, with Lisungwi EPA characterized by hot and dry conditions, while Neno EPA experiences
125 cool temperate conditions. These varying conditions significantly influence agricultural production
126 and enterprise performance.

127 **Figure 2: a) A map of the topography of Neno district b) A map of Neno district showing the**
128 **land use.** Source: Authors.

129 **2.2. Transportation in Neno district**

130 In Neno district, bicycles and motorcycles are the predominant modes of transportation.
131 Existing literature highlights that walking and *kabaza* (privately owned bicycle and motorcycle
132 taxis) are the dominant modes of passenger transport within Neno's trading centres and villages
133 (Palk et al., 2020). For journeys outside the district (mainly to Blantyre and Mwanza), vehicle
134 services, mainly minibuses, are limited, operating only up to two minibuses per day due to the lack
135 of tarred and paved roads (Figure 3) and challenging terrain (Aron et al., 2023; Palk et al., 2020).
136 This significantly complicates travel in the district, hindering access to vital services such as AES,
137 health care, markets, and other opportunities (Fraser & Haworth, 2017; Kachimanga et al., 2020).
138 Addressing these transportation challenges is essential to unlock Neno district's full potential for
139 economic growth and improved quality of life.

140 **Figure 3: A map of the road network in Neno district.** Sources: Authors.

141 **2.3. Factors associated with travel times**

142 We used an integrated geospatial framework to evaluate the travel times required by
143 farmers to access AES provided by NESMAC. This involved assembling spatial layers considered

144 essential factors in influencing travel time, such as the road network, land use, elevation, and travel
145 barriers.

146 **2.3.1. NESMAC Central Meeting Location (NCML)**

147 We collaborated with NESMAC staff to understand how their members access AES. The
148 NESMAC team explained how they strategically positioned their central meeting locations for
149 training delivery based on the proximity of their members, particularly lead farmers. Lead farmers
150 play an important role in training fellow farmers within their villages and clubs (Hermans et al.,
151 2020; Piñeiro et al., 2020). Aside from lead farmer training, extension workers occasionally visit
152 villages and clubs to provide additional support. However, they face several challenges including
153 limited access to transportation (motorcycles) and fuel funds which impact their efforts. Despite
154 these challenges, NESMAC remains committed to delivering AES effectively and strives to
155 maximize the available resources to support its members (Zuza et al., 2023).

156 **2.3.2. Road network**

157 We curated Malawi's road network by merging and refining data from multiple sources
158 (Palk et al., 2020). The baseline layer was established in 2005 using the *gold standard* Global
159 Positioning System (GPS) technique sourced from the Ministry of Transport and Public Works. It
160 was created using the *gold standard* Global Positioning System (GPS) technique to map coverage
161 of roads in 2005. Updates were incorporated from OpenStreetMap and Google Map Marker
162 following Macharia et al. (2021) approach. Using ArcGIS Pro version 2.8 (ESRI Inc., Redlands,
163 CA, USA), we ensured data quality by eliminating overlaps, digitization errors, and road segments
164 extending into water bodies.

165 **2.3.3. Elevation**

166 The slope of the land negatively affects walking and bicycling speeds (Moturi et al., 2022;
167 Ray & Ebener, 2008). We acquired slope data from the Shuttle Radar Topographic Mission at a

168 resolution of 30 m x 30 m. To account for walking speeds, we utilized Tobler's formulation as
169 described in Banke-Thomas et al. (2022), which is an exponential function that characterizes the
170 relationship between human walking speed and slope (Macharia et al., 2021; Ray & Ebener, 2008).
171 As for bicycling, the power correction was applied, ensuring that the speed increment attributed to
172 downward slopes did not exceed twice the speed on flat surfaces (Lee et al., 2023; Palk et al.,
173 2020).

174 **2.3.4. Land use – land cover**

175 We used satellite-derived land cover information to define the geographical space that
176 smallholder farmers navigate to access the training locations. This land cover data was obtained
177 from ESRI at a spatial resolution of 10 m x 10 m, featuring seven distinct classes: bare, sparse
178 vegetation, built-up areas, cropland, grassland, shrubland, tree cover, and permanent water bodies.
179 To access this data, we leveraged the Sentinel-2A satellite, launched in 2015 as part of the
180 Copernicus program jointly operated by the European Space Agency and the European Union.
181 Sentinel-2A provides high-resolution satellite data widely used for various applications, including
182 land cover and land use monitoring (Chemura et al., 2020). For consistency in our analysis, we
183 resampled the land use – land cover raster image to a uniform resolution of 30 m x 30 m. This step
184 ensured that all rasters used in our study had the same resolution, facilitating increased accuracy of
185 our results.

186 **2.3.5. Travel barriers**

187 The study incorporated various barriers such as permanent water bodies (rivers), forested
188 areas, national parks, and protected regions. These were considered impassable unless a bridge was
189 present where a road intersected a large body of water (Aron et al., 2023).

190 Table 1. Summary of data assembled, including factors that affect travel.

Category	Factor	Type	Year	Resolution	Source
List of meeting locations.	Central meeting location	Spreadsheet	2023	-	Nesmac staff
Factors affecting travel between meeting locations	Land cover/use	Raster	2022	30 m *	ESRI
	Elevation	Raster		30 m *	SRTM
	Transport barriers (Rivers)	Vector	-	-	Ministry of Transport and Open Street Map
	Road network	Vector	-	-	DIVA-GIS

191 **2.4. Modelling travel time**

192 To assess the travel time to the nearest NCML, we used the ‘accessibility module’ in
 193 AccessMod software (version 5.6.3) (Ray & Ebener, 2008). AccessMod utilizes the terrain-based
 194 least-cost path distance calculation to model travel time. We created a comprehensive dataset by
 195 merging the road network, land cover, elevation, water bodies, and protected areas using the "merge
 196 land cover" module in AccessMod. This dataset allowed us to apply different speeds for walking,
 197 cycling, motorcycling, and vehicles, considering various transport scenarios.

198 Our speed assignments for each road class, landcover type, and transport mode were based
 199 on an extensive review of spatial model parameterization from comparable studies in Malawi (Aron
 200 et al., 2023; Lee et al., 2023; Palk et al., 2020). In our geospatial model, farmers follow the most
 201 efficient path to reach the nearest NCML using various modes of transportation. If a road connects
 202 their village to the location in the shortest time, they will walk, cycle, or drive along the road. In
 203 areas with no roads, the farmer will find the path of least resistance, considering factors like
 204 vegetation and trees. For example, a farmer will walk, cycle, or drive along grassland to reach a
 205 nearby road that leads to the NCML, even if they have to take a grassland trail in the final stretch

206 to reach the location. This approach accounts for topography and various transport barriers,
207 accurately determining the least-cost path.

208 Our model provides valuable insights by estimating the time each NESMAC member
209 travels from their residence to the NCML to access agricultural extension services. We chose to
210 estimate travel time instead of solely measuring distance because it offers a more realistic measure
211 of geographical accessibility, encompassing various factors that affect actual travel time.

212 Further, we augmented our study with semi-structured interviews of expert and key
213 informant interviews to validate our assigned speeds for each travel scenario and explore the
214 district's AES issues. Experts and key informants were selected with purposive sampling based on
215 their knowledge and long understanding experience with agricultural extension systems in the
216 district (Bruce & Costa, 2019). This ensured we can gain a greater clarification on our research
217 objectives (Abdulai et al., 2023). A total of 10 semi-structured interviews were conducted. Experts
218 and key informants interviewed for the study included the district manager of NESMAC, the
219 district agricultural extension coordinator (AEDC), agricultural extension officers (AEDO), leaders
220 of NESMAC, and farmers with several years of experience. The Human Research Ethics
221 Committee of the Open University, United Kingdom, provided the ethical approval for the study.
222 Formal consent for participation in the study was obtained verbally from each participant.

223 The qualitative data from expert and key informant interviews were transcribed,
224 categorized, and interconnected with the spatial modelling data to build a narrative to develop a
225 comprehensive understanding of the access to agricultural extension services among smallholder
226 macadamia farmers in Neno district.

227 **3. Results**

228 **3.1. Availability of extension services and staff**

229 Malawi made a major revision to its agricultural extension approach at the turn of the new
230 millennium by introducing a policy that promotes pluralistic and demand-driven extension
231 systems. This policy shift has allowed the participation of other service providers apart from the
232 government, as evidenced by this study. We found that Neno district has eight non-governmental
233 organizations (NGOs) that are providing AES in collaboration with the District Agricultural
234 Development Office. Nonetheless, NESMAC is the only organization that offers AES associated
235 with macadamia production (Table 2). This is despite the introduction of the crop in the area three
236 decades ago. Most of the district's NGOs focus on providing AES for staple and cash crop
237 production, village savings and loans, climate change resilience and adaptation, farmer field
238 schools (FFS), and the management of non-communicable diseases and early childhood
239 development. A key informant indicated that:

240 “Because of our district's mountainous terrain, hot weather, and poor road networks, we are
241 sidelined in development activities. The majority of the activities are implemented by
242 Partners in Health (PIH), who have the infrastructure, such as personnel, 4 x 4 vehicles, and
243 motorcycles. As for the agricultural department, they only have one vehicle and a lot of
244 non-runner motorcycles and bicycles for the agriculture officers and lead farmers” (key
245 informant interview, Lisungwi EPA).

246 Table 2: Extension service providers and perceived objectives by farmers in the study area.

Name of AES provider	Type	Major activities implementing
District Agricultural Extension Services System (DAESS)	Government	<ul style="list-style-type: none"> - Affordable input program. - Conservation agriculture. - Nutrition & food processing. - Irrigation & dairy farming. - Good agricultural practices for common staple & cash crops. - Agribusiness. - Promotion of livestock production. - Market linkages.
Nesmac	Farmer-based organization (FBO)	<ul style="list-style-type: none"> - Production of macadamia. - Village savings & loans. - Climate change adaptation. - Payment for ecosystem services. - Promotion of agroforestry.
World Vision	NGO	<ul style="list-style-type: none"> - Irrigation and dairy farming. - Seed multiplication. - Food processing and utilization. - Community empowerment. - Promotion of financial services.
Food and Agricultural Organization of the UN	Multilateral organization	<ul style="list-style-type: none"> - Establishment of FFS. - Climate change resilience & adaptation.
PIH	NGO	<ul style="list-style-type: none"> - Distribution of goats for climate change adaptation. - Health & improved livelihoods.
MWASIP	NGO	<ul style="list-style-type: none"> - Village savings & loans. - Establishment of FFS. - Sustainable relief & development. - Microfinance.
IEYP	NGO	<ul style="list-style-type: none"> - Early childhood development. - Nutrition & food utilization.
Umodzi consulting	NGO	<ul style="list-style-type: none"> - Management of non-communicable diseases.
Concern Worldwide	NGO	<ul style="list-style-type: none"> - Conservation agriculture. - Irrigation farming. - Livestock production.

247 In the context of macadamia production, our findings suggest that extension service
248 providers lack specialized knowledge and skills in the area. An expert provided this insightful
249 remark during an interview:

250 “Although the AEDOs have received formal agricultural training, their knowledge
251 predominantly revolves around the application of management practices for staple
252 and cash crops. Macadamia production requires specialized knowledge, which is
253 limited in our agricultural education institutions. Therefore, this results in no
254 provision of training services for the macadamia farmers (extension officer, expert
255 interview, Lisungwi EPA).”

256 Additionally, we have discovered that the district has a limited number of government
257 extension officers, with six sections (2 in Lisungwi and 4 in Neno EPA) lacking extension officers.
258 Some AEDOs have also stepped up to work at the district level, leaving their sections unstaffed.
259 Moreover, we found that out of the 18 (Neno EPA) and 7 motorcycles (Lisungwi EPA), only 3 and
260 4 are runners, respectively. An expert remarked:

261 "We have over 32 bicycles available for the AEDOs, but with the mountainous
262 terrain, these are difficult to use."

263 Nonetheless, during another key informant interview, a female lead farmer commented:

264 “At the EPA, I have access to several bicycles designated to lead farmers.
265 Regrettably, the bicycles are old, worn out, and warrant immediate replacement.
266 Compounding the issue, there is an absence of allocated funds to facilitate the
267 repair of these bicycles despite our active contribution to the responsibilities of
268 the AEDOs. This has disincentivized many lead farmers, deterring our active
269 participation in providing extension services to farmers (lead farmer, key
270 informant interview, Neno EPA).”

271 **3.2. Challenges affecting the provision of macadamia extension services**

272 The outcomes of our study shed light on five significant challenges that impact the delivery
273 of macadamia extension services by NESMAC in Neno district. The following is a summary of
274 our results:

275 *3.2.1. Availability of extension staff and experts*

276 Macadamia is a relatively recent crop in Malawi, only introduced in the early 1960s for the
277 commercial estate sector. Our findings highlight a prevailing shortage of macadamia extension
278 staff and experts within the country. This has become even less available after the phasing out of
279 projects such as the Macadamia Smallholder Development Project (MSDP) by the African
280 Development Bank and the Farm Income Diversification Programme (FIDP) by the European
281 Union. An expert commented that:

282 “Majority of macadamia farmers are commercial estate producers compared to
283 smallholders. These commercial estate producers have invested in specialist
284 agronomists to provide tailored guidance for managing their macadamia orchards.
285 In contrast, smallholder farmers largely rely on the government and Nesmac for
286 their agricultural and macadamia extension needs. Also, agricultural education
287 institutions in Malawi do not offer comprehensive courses and training specific to
288 macadamia cultivation. These institutions predominantly focus on training
289 students on the management of staple and cash crops, leading to a gap in
290 specialized training for crops like macadamia (district extension officer, expert
291 interview, Neno DAESS).”

292 Consequently, in Malawi, the presence of government agricultural extension officers
293 equipped with the necessary training and skills to offer effective advice on macadamia management

294 is limited, if not absent. Nevertheless, we found that Nesmac addresses this gap by training its staff
295 with the help of specialists from the Neno Macadamia Trust (NMT) and The Open University, UK.

296 **3.2.2. Resource allocation**

297 The scarcity of resources poses a significant barrier to the effective delivery of evidence-
298 based agricultural recommendations and extension services. All ten respondents directly involved
299 in the provision of AES in Neno district mentioned a lack of resources, funding, and support for
300 macadamia research and extension services from both the government and NGOs. An expert
301 remarked:

302 “During the MSDP, farmers received weekly macadamia training provided by the
303 Malawi government extension officers. However, due to a lack of funding for the
304 macadamia value chain, extension officers currently focus on other crops, and
305 only NESMAC conducts the weekly training for their farmers. Hence, it is
306 imperative to allocate additional financial resources to bolster support for
307 organizations like NESMAC, which are actively engaged in delivering targeted
308 agricultural training programs (NESMAC manager, expert interview, Neno).”

309 Moreover, our study reveals that Nesmac is a primary provider of AES for macadamia
310 farmers in Neno district. The cooperative contributions from farmers themselves and earnings
311 from payment for ecosystem services schemes (Plan Vivo and Profs who Fly), coupled with
312 support from various donors, including the Cooperative College, GIZ, Imperial College London,
313 and NMT, collectively serve as essential sources of funds for sustaining and enhancing the delivery
314 of macadamia related AES.

315 **3.2.3. Lack of infrastructure**

316 Our findings also suggest that infrastructure, particularly the lack of properly paved roads,
317 substantially influences the provision of extension services for macadamia production in the study
318 area. The rugged terrain prevalent in the area poses a notable obstacle to movement and
319 accessibility, creating challenges in effectively delivering extension services. In addition, the
320 absence of well-paved roads exacerbates these issues, particularly during the rainy season when
321 unfavourable weather conditions render roads impassable. This negatively impacts the smooth
322 execution of training activities and crucial interactions between farmers and extension officers. A
323 key informant noted that:

324 “During the rainy season, the road surfaces become slippery with mud, and
325 bicycle use is restricted. Recent cyclones, namely Cyclones Ana, Freddy, and
326 Idai, bring flash floods that destroy roads and bridges, making some areas
327 inaccessible and thus affecting our contact with extension officers (male farmer,
328 key informant interview, Neno EPA).”

329 ***3.2.4. Policy framework***

330 The sustainability of the macadamia industry in Malawi depends on creating a policy
331 network that actively encourages macadamia production and offers thorough support for extension
332 workers. Our study reveals a significant gap in the current policy landscape in Malawi, in which
333 the government, despite being a major stakeholder in policy formulation, predominantly focuses
334 on maize and tobacco, sidelining other important value chains, such as macadamia. We find that a
335 lack of clear policies for the macadamia value chain has made it difficult to provide capacity
336 building for extension staff and services for farmers related to the production and marketing of
337 macadamia in the country. Hence, commensurate public expenditure and political alignment are
338 necessary to increase macadamia productivity among smallholder farmers.

339 **3.2.5. Lack of coordination and collaboration**

340 The results of our study show that there is insufficient coordination and collaboration
341 among stakeholders responsible for delivering extension services in Malawi, including Neno
342 district. This deficiency has resulted in a fragmented flow and unnecessary duplication of efforts.
343 Furthermore, this disarray among farmers has left them uncertain about which advice to adopt and
344 implement when making decisions about their crops, including macadamia. A key informant
345 indicated:

346 “We receive training on various technologies, such as financial management, from
347 various organizations implementing projects in the district. These organizations
348 provide some similar trainings; thus, it is challenging for us to take up the advice.
349 This is because of conflicting messages on the technologies, which lead to
350 confusion. For instance, we've received training on "merry-go-rounds" and
351 "village loans and savings," but to my understanding, these two concepts seem
352 quite alike. As such, it would be beneficial if the extension service providers could
353 establish a harmonized approach to communicating with us (female farmer, key
354 informant interview, Lisungwi EPA).”

355 **3.3. Spatial accessibility of macadamia extension services**

356 We have determined that Nesmac provides macadamia extension services to farmers in 82
357 villages (34 in Neno EPA and 48 in Lisungwi EPA) within the study area. Over 80% of these
358 villages have geographical barriers, particularly hills, rivers, and forested areas. These barriers
359 negatively impact the travel time to NCMLs. The results of the accessibility modelling to Nesmac's
360 central meeting locations using each transportation scenario are shown in Figure 4. The maps
361 reveal substantial inequities in the accessibility of NCMLs attributed to the geographical variations
362 in impediments caused by terrain and the mode of transportation used. We estimate that it takes

363 between 1 minute (driving on main roads) to 1 hour (walking in mountainous areas) to cross an
364 area of 1 km² in Neno district.

365 **Figure 4: Travel time (spatial accessibility) to the nearest Nesmac central meeting location**
366 **for four travel scenarios (a: walking only, b: bicycle only, c: motorcycle only, d: vehicle only)**
367 **classified into bins with better access (dark green) to most marginalized (red).**

368 Our study findings show that farmers' accessibility to NCMLs varies depending on their
369 mode of transportation. For the pessimistic scenario (walking only), the travel time to the nearest
370 NCML ranges from 0.1 to 789 minutes [20% uncertainty] and from 0.1 to 57 minutes for the most
371 optimistic scenario (vehicle only), with the rest of the scenarios being between these two extremes.
372 Furthermore, only one and two villages are within an hour's walk of Lisungwi and Neno NCMLs.
373 The outcomes from the pragmatic scenario (bicycle only) indicate that approximately 12.5% and
374 29.4% of the villages have access to NCMLs within 1-hour of travel time (overall 19.5%) in Neno
375 and Lisungwi, respectively. Under the optimistic (motorcycle only) and most optimistic (vehicle
376 only) scenarios, farmers from all of the villages in the study area can reach the NCMLs in less than
377 an hour. This demonstrates that motorized modes of transportation make NCMLs more accessible.
378 however, the travel times may be restricted and longer during the rainy season (November to April).

379 As expected, our modelling analysis proves that the mode of transportation limits the
380 catchment sizes of the NCMLs. Figure 5 shows the maximum catchment size of the two NCMLs
381 based on a maximum travel time of 1 hour and assuming that lead farmers can walk only (Figure
382 5a), use a bicycle only (Figure 5b), use a motorcycle only (5c), and use a vehicle only (5d).
383 Notably, when bicycles are used, the catchment area for Nesmac is significantly larger than if
384 individuals walk. The larger the catchments, the greater the number of farmers accessing
385 macadamia-related extension services. For example, the conditions shown in Figure 5a could result

386 in a maximum coverage of approximately 3.7%, those in Figure 5b in a maximum coverage of
387 approximately 19.5%, and those in Figure 5c and 5d in a maximum coverage of approximately
388 100%. These results illustrate that increasing the availability of reliable bicycles to lead farmers
389 and improving the road infrastructure in Neno district can substantially increase access to
390 macadamia extension services by expanding the area size of Nesmac catchments.

391 The results in Figures 4 and 5 indicate that the long distances farmers must travel to NCMLs
392 and the lack of transportation in Neno district are the major barriers to achieving very high coverage
393 levels. Additionally, our findings show that increasing the availability of bicycles to lead farmers
394 can greatly enhance their ability to access AES provided by Nesmac.

395 **Figure 5: Catchment size and maximum achievable coverage for extension service delivery**
396 **within 1-hour scenarios (a: walking only, b: bicycle only, c: motorcycle only, d: vehicle only).**

397 **4. Discussion**

398 **4.1 Availability of macadamia extension services and challenges**

399 One of the key approaches to achieving food security and reducing poverty in Malawi is
400 ensuring an adequate network of agricultural extension service providers staffed with qualified
401 personnel capable of training farmers. Our analysis reveals that Nesmac is the only farmer
402 organization offering AES related to macadamia management in Neno district. This is despite the
403 area being one of Malawi's most suitable and biggest areas for macadamia production (Evans,
404 2021; Zuza et al., 2023). The lack of macadamia extension service providers in the district is
405 attributed to the limited involvement of the Malawian government in the macadamia value chain,
406 confirming a previous report by Parshotam (2018). This is not surprising as Malawi's agricultural
407 policies are mainly oriented toward maize for food and tobacco for exports. Nevertheless, the
408 recent governmental policy shift towards commercializing high-value perennial crops, including

409 macadamia, underscores the urgency for the government to amplify its role within the macadamia
410 value chain.

411 Further, our investigation has confirmed that inadequate infrastructure, characterized by the
412 absence of tarred and paved roads, represents the foremost obstacle impeding the provision of AES
413 in the study area. This is corroborated by insights from key informants and experts highlighting
414 the significant challenges posed by Neno district's rugged mountainous terrain and the absence of
415 reliable public transportation. Collectively, these factors hinder lead farmers' access to NCMLs
416 where vital extension services are provided. These findings confirm and extend the work by Lee
417 et al. (2023), who found a negative and non-linear relationship between access to paved roads and
418 extension services, showing that access to AES decreased as a farmer's residence was farther away
419 from the nearest paved road.

420 We have also found that funding constraints affect the access to extension services among
421 macadamia farmers. Although lead farmers are provided with bicycles, our study has shown that
422 these bicycles are poorly maintained, and the majority need replacement. Moreover, during the
423 rainy season, the nature of the terrain and slippery roads make it difficult to use bicycles. As a
424 result, during this time of the year, a limited number of lead farmers attend training provided by
425 Nesmac. These findings are concurrent with Ragasa. (2020), who observed that poor mobility
426 (reliance on bicycles) among extension staff affected the provision of AES and was worse in hilly
427 areas. As such, it is recommended that Nesmac be supported with funding to hire more extension
428 staff and procure motorcycles and vehicles to increase their ability to reach more farmers in the
429 district.

430 **4.2. Spatial access to macadamia extension services**

431 To the best of our current knowledge, there is a lack of research on the spatial accessibility
432 for agricultural extension service delivery to smallholder macadamia farmers in Neno district,

433 Malawi. Our contribution lies in bridging this research gap by providing updated and context-
434 specific assessments of spatial accessibility scores within the study area. We focus on lead farmers
435 and their ability to access AES provided by Nesmac for four travel scenarios. The gridded surface
436 used in our analysis captures the local definition of a pluralistic extension system and local modes
437 of transportation, specifically walking, bicycle, and motorcycling. This approach makes our results
438 highly relevant for the formulation of localized policies.

439 Depending on the mode of transportation used, our findings demonstrate significant
440 variations in the accessibility of extension services and associated travel times to NCMLs. For the
441 pessimistic scenario (walking only), we found that most of the villages in the study area have
442 extremely limited access to AES provided by Nesmac. Consistent with previous studies in Kenya
443 (Moturi et al., 2022), Rwanda (Fadelu et al., 2022), and Zambia (Mroz et al., 2023), poor road
444 networks, spatial patterns of the villages, and geographical characteristics are the prominent factors
445 negatively affecting the walking duration to NCMLs in this study. Subsequently, farmers spend
446 more time walking (≥ 1 hour) to NCMLs than receiving training. Moreover, farmers are exhausted
447 due to the long distance travelled, hindering their concentration during training sessions. This is
448 exemplified in the remarks of a key informant:

449 “It takes 3 hours of walking from my village to the central meeting location in
450 Neno EPA. Because of the walking, I am already tired, and I spend the majority
451 of the training time napping and preparing myself for the long journey home. We
452 do know that Nesmac does not have enough funding for more extension officers,
453 but it would be great if we had village or cluster-based trainings as it would reduce
454 the travel times (male lead farmer, key informant interview, Neno EPA).”

455 Despite the pessimistic scenario, our results show that the use of bicycles (pragmatic
456 scenario) has the potential to substantially increase the catchment size and decrease the travel times

457 (≤ 1 hour) to NCMLs by the farmers. This suggests that if all Nesmac members had access to
458 reliable bicycles, the percentage of those having challenges accessing AES would decrease from
459 3.7% (for walking only) to 19.5%. Universal access to motorized transportation (motorcycles and
460 vehicles) would ensure that all Nesmac members can access extension services within an hour of
461 travel. However, the biggest impediments to achieving such ambitions (1-hour travel time to
462 NCMLs) are the poor road network, terrain, and the season during the year. Lack of motorized
463 transportation in rural areas of Malawi, particularly in Neno district, has already been identified as
464 a significant barrier to the provision of AES, access to markets, and medical care (FAO, 2022; Lee
465 et al., 2023). Moreover, most areas of Neno district are inaccessible during the rainy season due to
466 the lack of paved roads, which affects all modes of transportation, doubling the travel times,
467 especially the motorized ones, which also become expensive. Therefore, the government of
468 Malawi must consider improving the district's road infrastructure. Additionally, our study suggests
469 that Nesmac and the Malawi government collaborate on radio use for macadamia extension and
470 advisory services. This can assist in increasing the catchment sizes for the AES. An expert
471 informant highlighted that:

472 “The majority of smallholder farmers in Malawi have access to radios, televisions,
473 and mobile phones; therefore, combining radio with internet-based platforms and
474 utilizing interactive radio formats, such as calls, SMS, WhatsApp messages, and
475 participatory videos, can help reach more farmers and make agricultural extension
476 more cost-effective (District extension officer, expert interview, Neno).”

477 The results of our analysis provide other key insights. We have established that Nesmac
478 uses a hybrid approach in the provision of AES. In this method, Nesmac and the farmers agree on
479 a central meeting location to increase the accessibility of AES. Nonetheless, smallholders continue
480 to travel long distances to access AES from NCMLs, and extension officers have limited time to

481 visit their farms. Hence, it is recommended that the government provide funding to Nesmac to
482 increase the number of extension staff. Alternatively, to supplement Nesmac, the government
483 should employ more extension staff with expertise in macadamia management.

484 Regarding mode of transportation, context is important: motorized transportation,
485 especially motorcycles, is prevalent in the villages near the NCMLs. This is because these meeting
486 places are positioned in the two major trading centres of the district. Consequently, those villages
487 further from the trading centres continue to be marginalized and underserved by motorcycles.
488 Therefore, to increase the accessibility of macadamia extension services, Nesmac should begin
489 developing strategies for expanding its current catchment areas.

490 **5. Limitations**

491 Our study has some inherent limitations. To begin with, due to data limitations, several
492 conditions that affect travel speeds, such as weather, traffic congestion, and delays, were not
493 included in our analysis (Chênes et al., 2021; Banke-Thomas et al., 2022). However, a range of
494 speeds and their uncertainty represented the travel occurrences. Additionally, the road network
495 used in our study is somewhat outdated (it was created in 2005, and the government has not updated
496 it) and does not reflect recent changes in the road network in the study area. To address this issue,
497 we used OpenStreetMap and Google Maps to classify and update the various types of roads and
498 consulted with Nesmac staff to check if what we did represented what was on the ground.

499 **6. Conclusions**

500 In this study, we have employed spatial modelling data and semi-structured interviews to
501 examine the spatial accessibility and barriers to agricultural extension services in Neno district,
502 Malawi, for four travel scenarios involving local transport modes. Our study has revealed that in
503 Neno district, the proportion of villages (smallholder macadamia farmers) within 1-hour of the
504 nearest NCML varies between 3.7% (1 village in Neno and 2 in Lisungwi) when considering

505 walking only, 19.5% (6 villages in Neno and 10 in Lisungwi) when considering bicycles only, and
506 100% when both optimistic scenarios (motorcycles and vehicles) are considered. This provides a
507 foundation for national government policies related to road network infrastructure development
508 and public service delivery and has implications for achieving several SDGs, such as ending
509 hunger, eliminating poverty, ensuring access to education, and promoting responsible production.
510 To increase equitable access to macadamia-related AES in Neno district, the government should
511 prioritize road network development, hiring of more extension staff, particularly those with
512 expertise in macadamia management, allocation of resources to farmer organizations such as
513 NESMAC and HIMACUL, and the development of macadamia-related mass media programs.

514 **Data availability**

515 The raster data analyzed in this study is publicly on the [Malawi Spatial Data Platform](#),
516 [Shuttle Radar Topography Mission](#), and [The European Space Agency](#) websites. The village data
517 can be publicly accessed from the [National Statistical Office - Malawi](#) website.

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524 **Authors' contributions**

525 Conceptualisation: EZ, HT, YA; Methodology: EZ, HT, MGC; Formal analysis: EZ, HT,
526 MGC, AE, YA; Writing – Original draft: EZ, HT, AA; Writing – review & editing; MGC, YA,
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