

1 **Quantifying movement patterns and vaccination status of high risk mobile populations in**
2 **Pakistan and Afghanistan to inform poliovirus risk and vaccination strategy**

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4 Natalia A Molodecky^{1,2,3*τ}, Asma Usman^{1,2*}, Asif Javaid^{1,2}, Ashraf Wahdan^{1,2,4}, Edward PK Parker⁵,
5 Jamal A Ahmed^{1,2,7}, Nadeem Shah², John Agbor^{2,8}, Abdirahman Mahamud^{1,2,7} and Rana M Safdar^{2,6}

6 ¹World Health Organization (WHO), Islamabad, Pakistan

7 ²National Emergency Operations Centre for Polio Eradication, Islamabad, Pakistan

8 ³Department of Infectious Disease Epidemiology, Imperial College London, London, UK

9 ⁴World Health Organization (WHO), EMRO, Amman, Jordan

10 ⁵The Vaccine Centre, Faculty of Infectious and Tropical Diseases, London School of Hygiene and
11 Tropical Medicine, London, UK

12 ⁶Ministry of National Health Services, Regulations and Coordination, Islamabad, Pakistan

13 ⁷World Health Organization (WHO), Geneva, Switzerland

14 ⁸UNICEF, Islamabad, Pakistan

15

16 *authors contributed equally to this work

17 τ corresponding author

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20 **Short title**

21 Movement patterns of high risk mobile populations in Pakistan and Afghanistan

22 **Abstract**

23 **Background**

24 Stopping serotype 1 wild poliovirus transmission in Pakistan and Afghanistan requires ensuring all
25 children <5 years of age are repeatedly vaccinated, including the large proportion living in mobile
26 groups. Vaccinating children living in high-risk mobile populations (HRMPs) remains a priority for the
27 polio programme.

28 **Methods**

29 In 2017-2018, group-level censuses were conducted in 43 districts of Pakistan, gathering information
30 for all HRMP children <5 years of age residing in settlements. Demographic and mobility information
31 was collected, including HRMP type, ethnicity, language, mode of transportation and movement
32 patterns. Vaccination status was recorded for the most recent polio campaign. Proportion of HRMP
33 children by demographic factors and mode of transportation was determined and the magnitude of
34 movement was quantified based on the origin, previous and next locations. Magnitude of cross-border
35 movement with Afghanistan was evaluated, as was primary crossing point. Vaccination status was
36 evaluated for each district by demographic and mode of transportation information.

37 **Results**

38 In total, 188,130 HRMP children <5 years of age were assessed. The predominant HRMP type, ethnic
39 group, language and mode of transport was Afghan refugees (27%), Pashtun (69%), Pashto (69%) and
40 bus (52%). Overall, 84% of children originated outside of their current district, including 29% from
41 Afghanistan. Previous and next locations, were reported outside of current location by 34% and 77%
42 of children. Afghanistan was previous and next location for 5% and 11% of children, with 5.5% and 3%
43 of children crossing the Afghanistan border in the past 6-months and next 3-months. Primary crossing
44 route was Torkham (79%). Overall vaccination coverage was 98% (IQR: 96%-99%) and consistently
45 >90% across HRMP type, ethnic group, language and mobility means.

46 **Conclusion**

47 Large numbers of HRMPs were found across Pakistan, with substantial links throughout the country
48 and with Afghanistan. While vaccination coverage of HRMPs was high, ensuring these populations are
49 consistently vaccinated remains a priority.

50

51

52 **Background**

53 Continued transmission of serotype 1 WPV (WPV1) in Pakistan and Afghanistan (the final two
54 poliovirus endemic countries) remains arguably the greatest obstacle to achieving global polio
55 eradication. In 2020, 140 WPV1 cases were reported globally, 84 from Pakistan and 56 from
56 Afghanistan [1]. Given the current context of SARS-CoV2 transmission (which resulted in temporary
57 pause of vaccination campaigns [2] and subsequent logistical challenges in conducting high quality
58 campaigns), the polio programme may face a further increase in reported WPV1 cases in 2021. This
59 challenge is compounded by an ongoing outbreak of serotype-2 circulating vaccine-derived poliovirus
60 (cVDPV2) across this epidemiological block since July 2019 resulting in 427 cases (as of 1 Feb 2021).

61 Eradication of WPV1 (and stopping outbreaks of cVDPV2) will require high vaccination rates to be
62 maintained via routine and supplementary immunization activities. Achieving this is challenging due
63 to vaccine hesitancy, community campaign fatigue, inaccessibility (including bans on door-to-door
64 vaccination campaigns in select high-risk areas of Afghanistan), political instability and violence
65 against front-line workers, particularly in the regions on either side of the Afghanistan–Pakistan
66 border [3, 4]. Compounding these challenges is the highly mobile nature of the populations in Pakistan
67 and Afghanistan, with frequent movement between districts, provinces and across the international
68 border.

69 Poliovirus predominantly persists in the shared transnational transmission corridors in eastern
70 Afghanistan/northwestern Pakistan and southern Afghanistan/southwestern Pakistan, as well as in
71 the city of Karachi. Transmission in these hotspots as well as exportation and subsequent local
72 transmission is fueled by the highly dynamic and frequent population movement within and between
73 these two countries. Population movement is relatively high, especially in Pakistan, with millions of
74 people travelling between districts each day [5]. Travel is often long-distance and predominantly
75 follows a northwest–southeast pathway, with large volumes occurring to and from Karachi [5].

76 Movements are prompted by a variety of factors, including economic motivations, climate/weather
77 patterns and ethnic/cultural links. Moreover, a substantial amount of movement occurs between
78 Pakistan and Afghanistan. Four decades of war and conflict have forced millions of Afghans out of
79 their homes and into Pakistan [6]. In 2020, the number of registered Afghans living in Pakistan was
80 estimated to be >1.4 million (with an additional ~1 million estimated to be unregistered)[6, 7]. These
81 movement patterns have resulted in strong ties between communities on either side of the border,
82 supporting continuous and dynamic movement. Currently, the majority of Afghans travelling to and
83 from Pakistan are temporary migrants, with movements primarily for social and economic reasons [6].
84 Therefore, the movement patterns now follow a more regular, cyclical pattern, with many Afghans
85 maintaining a base in both countries.

86 Children in these mobile groups are expected to be under-immunized, as they are often on the move
87 and miss opportunities for polio vaccination through routine immunization or supplementary
88 immunization activities (SIAs). As such, they are likely at heightened risk of propagating poliovirus
89 transmission. This is particularly true for communities moving from northwest Pakistan and in and out
90 of Karachi, which have reported the lowest vaccination coverage rates in the country [8, 9]. The
91 substantial volume of movement between Pakistan and Afghanistan results in continuous re-infection
92 and persistent poliovirus transmission across the border, notably through the two main transit routes
93 of Chaman (Friendship Gate) and Torkham. This border-spanning WPV reservoir is evident through
94 the continuous detection of genetically linked poliovirus through environmental surveillance on either
95 side of the Pakistan–Afghanistan border [10].

96 Thus, a challenge confronting the polio programme in Pakistan and Afghanistan has been how to
97 effectively reach and vaccinate the large numbers of children living in high-risk mobile populations
98 (HRMPs). Due to the transient nature of these groups, identifying and tracking them has been a
99 challenge; therefore, the polio programme has implemented many initiatives to ensure vaccination of
100 HRMP children. To ensure the vaccination of migrant children moving to/from the core reservoirs and

101 across the international border with Afghanistan, permanent transit posts (PTPs) at borders (including
102 between districts, provinces and nations) have been established [11]. From July 2016 to May 2017, a
103 total of 15,854,636 children were vaccinated at PTPs, including those at the Pakistan–Afghanistan
104 international border [11]. Moreover, special focus has been placed on ensuring these populations are
105 tracked and incorporated into SIA planning (e.g. operational microplans — comprehensive campaign
106 plans, including number and location of children living in an area [12, 13]), monitoring and evaluation.
107 Ensuring HRMPs are systematically mapped and vaccinated remains a key strategic priority in
108 Pakistan’s National Emergency Action Plan (NEAP) for Polio Eradication 2020 [14]. Here, we present
109 the results of a district-level census of HRMPs, including their demographics, movement patterns and
110 vaccination status. These assessments provide a better understanding of the effectiveness of the
111 current strategies to target these high risk groups, the remaining gaps and magnitude of polio
112 transmission risk posed by HRMPs. This work has directly informed operational strategies (e.g.,
113 targeted surveillance, implementation or strengthening vaccination at key PTPs, strengthening HRMP
114 components of operational microplans, etc.) aiming to ensure these populations are consistently
115 being reached.

116 **Methods**

117 **District-level assessments**

118 Between July 2017 and January 2018, HRMP assessments were conducted in 43 districts of
119 Balochistan, Punjab, Khyber Pakhtunkhwa (KP), KP Tribal Districts (KPTD) and Sindh (Fig 1A). The 18
120 towns of Karachi were assessed separately; however, they were combined into one district for
121 analysis. The assessed districts were selected by prioritizing areas at increased risk of poliovirus
122 transmission, including large population influxes and connectivity with infected districts, based on the
123 Pakistan district-level risk classification [11, 14, 15]. Specifically, the majority of districts classified as
124 either Tier 1 (core reservoirs) and Tier 2 in the NEAP [11] based on Pakistan district-level risk (methods

125 described in [16]) were included in the assessment (Khyber, North Waziristan, Mohmand and Bajour
126 were excluded due to security challenges during the assessments). Select Tier 3 and Tier 4 districts
127 that directly bordered the Tier 1 and 2 districts were also included.

128 The HRMP assessments were group-level censuses, whereby information was gathered for all HRMP
129 children <5 years of age in all HRMP settlements of a district. HRMP populations were defined as any
130 vulnerable special population that are either displaced (internally-displaced, Afghan refugees, or
131 returnees) or move regularly for economic or weather-related reasons (e.g. nomads, seasonal
132 migrants, brick kiln workers, agricultural migrant labour, other vulnerable economic migrants). HRMPs
133 were classified into eight types based on their primary purpose of travel, including: nomads, seasonal
134 migrants, agricultural migrants, brick kiln workers, economic migrants, internally displaced persons
135 (IDPs), returnees and Afghan refugees (specific definitions for HRMPs are provided in Table S1). An
136 HRMP group was defined as any number of families (≥ 2) of the same demographic information (i.e.
137 HRMP type, tribe, sub-tribe, ethnicity, language, mobility means) and movement patterns (i.e. origin,
138 previous and next locations, and timings of movement). Settlement was defined as any identifiable
139 area where one or more HRMP groups are residing. All settlements in each district were visited by the
140 assessors (polio programme staff). The assessors were assigned to a specific Union Council (UC) and
141 asked to identify HRMP settlements within their assigned UCs with the help of programme microplans
142 and local guides. They then interviewed the settlement leader to determine how many HRMP groups
143 (i.e. same demographics, movement patterns, timing of movement) were residing in the settlement.
144 If only one group, the settlement leaders completed the questionnaire and included the number of
145 children <5 years of age within the group. If more than one group, each group leader was separately
146 interviewed. Prior to any data collection, the assessors explained the rationale and utility of the
147 assessment and obtained verbal consent. Because the data collection constituted standard
148 operational polio programme activities in Pakistan, it was not governed by an institutional review
149 board.

150

151 The assessors collected demographic and mobility information for each HRMP child <5 years of age,
152 (including movement patterns, ethnicity, language, mode of transportation, cross-border movement
153 with Afghanistan) from the settlement or group leaders. For movement patterns, the origin, previous
154 and next locations for each child was recorded. Origin location was place of birth or location with
155 strong cultural and/or familial ties. Previous location was based on a 6-month time interval prior to
156 data collection to reflect recent travel, as major operational plans are revisited bi-annually to create
157 the National strategy (i.e. NEAP). For next location, a shorter time frame of 3-months was selected to
158 capture any immediate travel plans as many people are not yet aware of their next location. Locations
159 were aggregated at district level for Pakistan and province level for Afghanistan.

160 All children <5 years of age across all HRMP groups and all settlements were checked for vaccination
161 status for the most recent SIA; however, if a single HRMP group included >7 families, 7 families were
162 randomly selected and the vaccination status of all children in these 7 families was taken. Therefore,
163 while the demographic information and movement patterns were census level for all HRMP children
164 <5 years of age in the assessed locations, vaccination status reflects a sample of all children from up
165 to 7 families within each HRMP group. Assessments were conducted in two rounds: in the first round,
166 22 districts were assessed and vaccination status was determined based on parent recall; in the
167 second, 21 districts were assessed and vaccination status was determined based on finger mark
168 (standard method of marking a vaccinated child following immunization). The assessments were
169 conducted immediately following SIAs (whenever possible National SIAs) during the post-campaign
170 evaluation phase. The location of the children during the SIA was confirmed to be the assessed
171 location during data collection. All data were collected using Open Data Kit, a software for collecting,
172 managing and using data in resource-constrained environments [17].

173 **Statistical analyses**

174 Demographic and mobility information, including HRMP type, ethnicity, language and mobility means,
175 was evaluated for each assessed district and for the overall study population. Specifically, the
176 proportion of HRMP children <5 years of age across demographic factors and mode of transportation
177 was determined. Moreover, for each district, the magnitude of movement was quantified based on
178 the origin, previous and next locations of the HRMP groups (based on the number of children <5 years
179 of age moving into and out of the district). The magnitude of movement was also determined for each
180 HRMP type. Additionally, the proportion of children <5 years of age in the district that reported the
181 origin, previous and next location to be the assessed district was evaluated. Cross-border movement
182 patterns between Pakistan and Afghanistan were evaluated, including the number of children <5 years
183 of age crossing the border in the past 6-months and next 3-months, as well as the primary border
184 crossing point. The vaccination status of HRMP children <5 years of age was evaluated for each district
185 by demographic and mobility information, including origin location. All analyses were conducted using
186 the R programming language [18].

187 **Results**

188 In total, 188,130 children <5 years of age were assessed across 43 districts (Fig 1B). The median
189 number of children assessed in the included districts was 2,920 (IQR: 1,501–6,412). There were two
190 districts in which >10,000 children were assessed (Nowshera and Karachi). There were 13,785 groups
191 and 101,685 families assessed, with a median of 3 (IQR: 2-7) families and 6 (IQR: 3-12) children per
192 group. There were 2,435 (18%) groups with >7 families, with a median of 14 (range: 8-800) families in
193 these groups. 48 children with unknown origin were excluded from the analysis.

194 Here, we present the demography, movement patterns and vaccination status for the overall HRMP
195 survey population. We also present district-level data for Peshawar, Karachi and Killa Abdullah (KAB)
196 owing to their critical role in sustaining poliovirus transmission within Pakistan. These three districts
197 are core reservoirs of poliovirus and consistently classified as highest risk based due to their high
198 population density, sub-optimal vaccination coverage and/or substantial movement patterns across

199 Pakistan and Afghanistan. The assessments in these districts included 8,361, 12,658 and 2,441
200 children, respectively. Results from all other assessed districts are presented in Supplementary Text
201 1.

202 *Demography*

203 Of all children assessed, the predominant HRMP type was Afghan refugees (50,812 [27%]), followed
204 by nomads (39,774 [21%]), seasonal migrants (28,550 [15%]), agricultural migrants (19,652 [10%]),
205 economic migrants (16,989 [9%]), IDPs (16,827 [9%]), brick kiln workers (14,818 [8%]) and returnees
206 (708 [0.4%]) (Fig 1C). The predominant ethnic group was Pashtun (130,511 [69%]), followed by Siraiki
207 (19,975 [11%]), Sindhi (10,958 [6%]), Punjabi (9,662 [5%]) and Baloch (6,984 [4%]). The predominant
208 languages were Pashto (129,720 [69%]), Siraiki (20,858 [11%]) and Sindhi (11,026 [6%]). The primary
209 mode of transport was bus (93,868 [52%]), followed by trolley (45,423 [25%]), foot (23,880 [13%]) and
210 car (16,726 [9%]).

211 Results for Peshawar, Karachi and KAB are shown in Fig 1C. Afghan refugees were more common in
212 Peshawar and KAB than the overall survey population (4,676 [56%] and 1,163 [48%], respectively),
213 while in Karachi, Afghan refugees were less common (682 [5%]) and nomads were the most HRMP
214 type (5,456 [43%]), followed by economic migrants (2,729 [22%]) and agricultural migrants (2,188
215 [17%]). The predominant ethnic group was Pashtun in both Peshawar and KAB (8,029 [96%] and 2,305
216 [94%], respectively), while the HRMP population in Karachi comprised a more diverse range of ethnic
217 groups, with Sindhi (4,444 [35%]) Punjabi (2,534 [20%]) and Pashtun (2,154 [17%]) the most
218 common. The primary mode of transport was bus in both Peshawar and Karachi (4,645 [56%] and
219 11,001 [87%], respectively), and was not reported in KAB (mode of transportation was added to the
220 questionnaire following the assessment in Quetta Block in July 2017).

221 *Movement patterns*

222 Origin location was reported for all HRMP children. A total of 171 origin locations were given, with
223 157,728 (84%) children originating outside of their current district, including 54,343 (29%) originated
224 from Afghanistan. The most common origin locations were South Waziristan (15,568 [8%]), Nangarhar
225 (13,803 [7%]), Kabul (9,523 [5%]), Logar (7,837 [4%]), Bajour (7,066 [4%]) and Quetta (6,742 [3.5%]).
226 At province level, 34,287 [18%] children had an origin in KPTD, 20,800 [11%] in Sindh, 27,639 [15%] in
227 Balochistan, 19,325 [10%] in KP and 31,633 [17%] in Punjab.

228 Among children in Peshawar, Karachi, and KAB, 7,632 [91%], 11,669 [92%] and 1,727 [71%],
229 respectively, did not originate in their current district (Fig 2C). Afghanistan was the origin of 5,342
230 [64%] children in Peshawar, 309 [2%] in Karachi and 1,572 [64%] in KAB. Of the three districts, children
231 in Karachi had the most diverse range of origins (106 locations reported), followed by Peshawar (75)
232 and KAB (22).

233 Data on previous location were obtained for 180,966 (96%) of the children surveyed, while next
234 location was reported in 47,302 (25%). A total of 159 different previous locations and 143 next
235 locations were reported, of which 62,375 (34%) and 36,531 (77%), respectively, were outside of the
236 participant's current location. The most common previous locations were Nowshera (22,260 [12%]),
237 Dera Ismail Khan (DI Khan) (8,926 [5%]), Hangu (8,191 [4.5%]), Kohat (6,475 [3.6%]), Peshawar (6,074
238 [3.4%]) and South Waziristan (5,987 [3.3%]), while the most common next locations were South
239 Waziristan (6,245 [13%]), Quetta (4,503 [9.5%]) and DI Khan (3,501 [7%]). Afghanistan was the
240 previous location for 9,713 (5%) children surveyed and the next location for 5,116 (11%).

241 Previous location was reported for 7,970 (95%), 11,922 (95%) and 2,441 (100%) participants in
242 Peshawar, Karachi and KAB, respectively. Of these, 2,593 (32%), 7,728 (64%) and 468 (19%),
243 respectively, were outside of the present district, and 1,181 (15%), 59 (0.5%) and 411 (17%),
244 respectively, were in Afghanistan. The range of previous locations was most diverse for Karachi (77),
245 followed by Peshawar (59) and KAB (11).

246 Reporting rates for next location varied markedly among districts (1366 [16%] in Peshawar, 1391
247 [11%] in Karachi, and 2,441 [100%] in KAB). Overall, 75% of those assessed were unsure of their next
248 location. Of those reporting next location, 1071 (78%), 1272 (91%) and 1101 (45%), respectively, were
249 outside of the district. The range and frequency of next locations reported in each district generally
250 overlapped with the range of previous locations. Notably, next locations in Afghanistan were reported
251 for 457 (33%) children in Peshawar, 25 (2%) in Karachi and 1017 (42%) in KAB. The range of next
252 locations was most diverse for Peshawar (45), followed by Karachi (43) and KAB (14).

253 A total of 9,684 (5.5%) of children assessed were reported to have crossed the border with Afghanistan
254 in the past 6-months and 4,419 (3%) were to do so in the next 3-months (out of 175,369 children with
255 information available on previous crossing and 166,935 children on subsequent crossing). The districts
256 with greatest number of children crossing from Afghanistan in past 6-months included Nowshera
257 (2,318 [24%]), Charsada (2,207 [23%]), Peshawar (1,194 [12%]), Swabi (1,143 [12%]) and Kohat (760
258 [8%]); and into Afghanistan in next 3-months included Charsada (1,598 [36%]), Hangu (1,171 [26%]),
259 Peshawar (832 [19%]), Nowshera (317 [7%]) and Mardan (117 [3%]). The primary route of crossing
260 was Torkham border, which was used by 7,650 [79%] of participants; 663 (7%) used Chaman border
261 and the remaining 14% used other formal and informal routes.

262 *Vaccine coverage*

263 The overall vaccination coverage across all assessed districts was 98% (IQR: 96%-99%) (Fig 3). For the
264 22 (n=48,234) and 21 (n=57,472) districts assessed in Rounds 1 and 2, respectively, the median
265 vaccination coverage was 98 (IQR: 96%-99%) and 98% (IQR: 94%-99%), respectively. 20 (91%) and 21
266 (100%) of assessed districts reported $\geq 90\%$ vaccination coverage in rounds 1 and 2, respectively. The
267 two districts with vaccination coverage $< 90\%$ in round 1 were Zhob (84%; n=971/1,159) and Sherani
268 (65%; n=355/547). Vaccination coverage was consistently $> 90\%$ across HRMP type, ethnic group,
269 language and mobility means (apart from language Shina, with very small sample, n=5). Coverage was

270 97% (95% CI: 96%-97%) in Peshawar, 92% (95% CI: 91%-93%) in Karachi and 97% (95% CI: 96%-98%)
271 in KAB.

272 Of the total unvaccinated children (N=2,795), the greatest proportion by HRMP type were nomads
273 (36.6% [95% CI: 34.8-38.4%]), followed by seasonal migrants (21.0% [19.5-22.5%]) (Fig 4A). Afghan
274 refugees represented 8.6% [7.6-9.7%] of the unvaccinated children. Nomads represented a greater
275 proportion of unvaccinated compared to vaccinated children (vaccinated: 26.3% [26.0-26.5%]) as did
276 seasonal migrants (vaccinated: 15.4% [15.2-15.6%]), while Afghan refugees accounted for a smaller
277 proportion (vaccinated: 19.1% [18.9-19.3%]). The greatest proportion by ethnic group were Pashtuns
278 (51.8% [49.9-53.6%]), followed by Sindhi (14.7% [13.4-16.1%]). Sindhi ethnic groups represented a
279 greater proportion of unvaccinated versus vaccinated children (vaccinated: 6.0 [5.8-6.1%]), while
280 Pashtuns accounted for a smaller proportion (vaccinated: 62.8% [62.5-63.1%]). These differences in
281 ethnic group were reflected by corresponding discrepancies in language type. For mode of
282 transportation, the greatest proportion of unvaccinated children travelled by bus (43.6% [41.7-
283 45.6%]), followed by trolley (27.5% [25.7-29.2%]) and foot (25.6% [23.9-27.3%]). Unvaccinated children
284 were unlikely to travel by car (3.3% [2.7-4.1%]). Travel by foot represented a greater proportion of
285 unvaccinated compared to vaccinated children (vaccinated: 13.8% [13.6-14.0%]), while travel by bus
286 accounted for a smaller proportion (vaccinated: 48.9% [48.6-49.2%]). The most common origin
287 location of unvaccinated children was South Waziristan (14.1% [12.8-15.4%]), followed Quetta (5.5%
288 [4.7-6.4%]), DI Khan (4.6% [3.8-5.4%]), Jacobabad (4.0% [3.3-4.8%]), Nangarhar (3.4% [2.8-4.1%]),
289 Dadu (3.1% [2.5%-3.9%]) and Zhob (2.4% [1.8-3.0%]) (Fig 4B). The origin location represented a greater
290 proportion of unvaccinated compared to vaccinated children in South Waziristan (vaccinated: 6.7%
291 [6.6-6.9%]), Quetta (vaccinated: 3.0% [2.9-3.1%]), DI Khan (vaccinated: 2.5% [2.4-2.6%]), Jacobabad
292 (vaccinated: 1.4% [1.3-1.4%]) and Dadu (vaccinated: 1.5% [1.5-1.6%]), whereas the reverse was true
293 in Nangarhar (5.2% [5.1-5.3%]).

294

295 **Discussion**

296 In 2020, Pakistan and Afghanistan were the only countries to report indigenous WPV1-associated
297 poliomyelitis. Substantial challenges remain in stopping WPV1 transmission in this epidemiological
298 block and ensuring all children <5 years of age are being repeatedly vaccinated. These challenges are
299 exacerbated by the highly mobile nature of this population requiring successfully tracking and
300 reaching HRMP children on the move.

301 To better understand the movement patterns of HRMPs and assess how well they are being
302 vaccinated, the Pakistan polio programme conducted census-level assessments of mobile populations
303 across areas at high risk of WPV1 transmission in Pakistan. In this work, we found that there are
304 substantial numbers of HRMPs across all provinces in Pakistan. The greatest numbers of HRMPs were
305 reported in the highly-populated districts of Nowshera and Karachi. These districts are well-connected
306 throughout Pakistan and Afghanistan and therefore pose a great risk of propagating poliovirus
307 transmission. Moreover, the predominant ethnic group of assessed HRMPs was Pashtuns, a group
308 known to be highly mobile with ethnic links throughout Pakistan and Afghanistan.

309 The HRMP assessments emphasize the substantial population movement that occurs within Pakistan.
310 The majority of assessed children reported their previous location within Pakistan, with the largest
311 proportion coming from KP province. There were substantial numbers of HRMPs originating across all
312 provinces in Pakistan, indicating that movement within Pakistan is widespread and often long-range.
313 Given the significant volume of movement within Pakistan, our study highlights the importance of
314 PTPs at inter-district and inter-provincial (as well as international) borders. In addition to the
315 considerable movement within Pakistan, there was substantial cross-border movement between
316 Pakistan and Afghanistan. The predominant HRMP type of all assessed districts was Afghan Refugees,
317 supporting the strong links between the two countries. Moreover, Afghanistan was reported as the
318 origin location in a large proportion of children, while a substantial number were reported to have
319 crossed the border with Afghanistan in the past 6-months or planned to cross in the next 3-months,
320 particularly using the northern corridor route.

321 A few key districts, including Peshawar, Karachi and Killa Abdullah, play a critical role in sustaining
322 poliovirus transmission within Pakistan and are highly connected across the country and/or with
323 bordering Afghanistan. In Peshawar, the HRMPs were primarily Afghan Refugees with strong ties to
324 Nangarhar, Kunar and Kabul in Afghanistan. This is supported by historical epidemiology linking
325 continuous poliovirus transmission in Peshawar with the Greater Nangarhar area [10, 19]. The primary
326 mode of transport of these groups was bus, indicating targeting bus routes across the Torkham border
327 through PTPs may be a useful strategy for mitigating the risk of cross-border transmission. In addition
328 to the links with Afghanistan, a substantial amount of movement occurs within Peshawar, which may
329 play a role in sustaining local transmission, particularly in instances where gaps in vaccination coverage
330 result in pockets of susceptibles throughout the district.

331 In Karachi, where large volumes of travel occur to and from the district, there were >12,000 reported
332 HRMP children <5 years of age. The HRMPs in Karachi were predominantly nomads; however, there
333 was also a large proportion of economic and agricultural migrants. Although the predominant ethnic
334 group and language was reported as Sindhi (followed by Punjabi and Pashtun), all ethnic groups were
335 represented, supporting the large diversity of migrants into and out of Karachi. HRMPs in Karachi were
336 reported from all provinces, with >100 districts as origin location, highlighting the wide-spread and
337 long-distance nature of movement patterns to/from Karachi. While only 8% of assessed children in
338 Karachi originated from Karachi, 36% reported Karachi as their previous location (i.e. remained in
339 Karachi for \geq 6-months), indicating that a substantial amount of movement also occurs within Karachi.
340 The patterns of poliovirus detection in environmental surveillance of Karachi supports these
341 movement dynamics, demonstrating strong links of transmission between Karachi and the rest of
342 Pakistan as well as locally between the different Karachi towns. In light of this dynamic situation, the
343 polio programme in Karachi (and all high-risk areas of Pakistan) has placed an increasing emphasis on
344 ensuring HRMPs are being included in local operational microplans. Moving forward, these must be
345 routinely updated to reflect changes in HRMP groups.

346 In Killa Abdullah, the assessed children were primarily Afghan Refugees (followed by nomads and
347 seasonal migrants) and primarily Pashtun. There were strong links with Greater Kandahar in
348 Afghanistan, with >60% of children reporting an origin location in bordering areas of Afghanistan,
349 highlighting the importance of ensuring that PTPs at the border crossing point are well equipped to
350 vaccinate all children during transit. Despite the strong links with Afghanistan, the main reported
351 origin, previous and next location of travel was Killa Abdullah, substantiating large settled HRMPs in
352 the district. This poses a potential risk to sustained location transmission if these populations are not
353 being reached through vaccination strategies. Despite the highly mobile nature of the populations
354 moving into/out of and within Peshawar, Karachi and Killa Abdullah, these groups tend to be very well
355 vaccinated, with coverage rates consistently >90%, highlighting the strategies targeting these groups
356 (e.g. PTPs, microplans) are effectively reaching these high risk populations.

357 The overall vaccination coverage of HRMPs was very high, with >90% coverage reported across the
358 majority of assessed districts. The high coverage was consistent across HRMP type, ethnic group,
359 language and mobility means, indicating that programme operations are able to reach and vaccinate
360 HRMPs. These results are reassuring, especially the success in reaching groups that have been a
361 primary focus for the programme, including Afghan Refugees, Pashtuns and HRMPs travelling by bus
362 (as indicated by these groups being disproportionately represented in the vaccinated group);
363 however, gaps likely remain in ensuring these populations are being vaccinated consistently,
364 particularly while crossing the border with Afghanistan using informal routes. The results highlight
365 that additional strategies focusing on ensuring nomads and seasonal migrants are captured (especially
366 those of Sindhi ethnicity and language) will help ensure all HRMPs are consistently being reached.
367 Moreover, special emphasis should be placed on HRMPs with origin and/or ties to South Waziristan
368 (also Quetta and DI Khan), which represented the greatest diaspora of HRMPs and a disproportionate
369 number of unvaccinated children. Moreover, given that >95% immunity is often required in these high
370 transmission settings [20], coupled with suboptimal routine immunization coverage in many parts of
371 Pakistan where high proportions of HRMPs reside [21] and high prevalence of factors that directly

372 impede child-level immunity (e.g. suboptimal vaccine response)[22], consistently high SIA coverage
373 rates are particularly important. Therefore the programme must remain vigilant given the continued
374 risk these populations pose for continued poliovirus transmission.

375 In this work, we present the results from a detailed assessment of HRMPs, including the demography
376 of these mobile groups, their movement patterns and vaccination status. Given this strong
377 infrastructure and local knowledge of the polio programme in Pakistan, we believe the identification
378 of HRMP settlements to be comprehensive. Despite the depth and utility of this information, several
379 limitations should be highlighted. First, the assessments were conducted at one point in time and
380 therefore provide only a snapshot of the HRMP groups within a district. Moreover, the districts were
381 assessed in different months of the year making inference between the districts difficult. Second, the
382 vaccination status was determined using different methodology in the first and second rounds (i.e.
383 recall and finger-marking, respectively; the latter which is considered the gold standard for the polio
384 programme). Comparing vaccination coverage between rounds demonstrated no marked difference
385 (i.e. >90% irrespective of methodology used to determine vaccination status). It was not possible to
386 confirm vaccination status through vaccination card, as cards reflect vaccination history through
387 routine immunization services in infancy and are not marked for vaccine doses given during polio SIAs
388 targeting children up to 5 years age [21]; card retention is also very low in this population [23].
389 However, previous assessments of routine immunization in Pakistan demonstrated comparability
390 between coverage based on recall and card [21]. Third, vaccination status was based on the most
391 recent SIA dose which does not reflect the consistency of vaccination coverage. Follow-up
392 assessments and/or seroprevalence studies in this population may help discern the consistency at
393 which HRMP children are vaccinated and their immunity profiles, respectively. Fourth, the vaccination
394 status was only considered for up to 7 families per group. While the median number of families per
395 group was 3 (IQR: 2-7), there were 18% of groups with >7 families. We would expect families in the
396 same group to behave similarly, and within groups coverage was either 0% or 100% for 92.4% of
397 groups. Therefore, while some families were excluded from the results, the results likely reflect group-

398 level coverage. Finally, 75% of children were unsure of their next location; therefore, the results for
399 next location may not fully capture the onward movements of the HRMP groups. Despite these
400 limitations, the results from these assessments provide valuable information on movement patterns
401 and vaccination status of a vulnerable population in Pakistan.

402 In the current context of ongoing SARS-CoV-2 transmission, the impacts of infection prevention and
403 control (IPC) measures (including lockdowns and restricted travel) on overall movement patterns in
404 Pakistan are not yet fully clear. However, while there appeared to be modest overall reduction in
405 movement, particularly in mid-late 2020, the movement patterns have returned to near baseline
406 levels based on daily accounts of movement from Google's COVID-19 Community Mobility Reports for
407 Pakistan [24]. The lack of substantial impact of the pandemic on movement patterns is due to the lack
408 of complete adherence to IPC strategies by the general population in Pakistan [25, 26] and early
409 conversion of National lockdowns to 'smart' lockdowns ensuring strict closure of COVID-19 hotspots
410 while the rest of the country's economy remained largely open. Therefore, while COVID-19
411 restrictions will likely continue to have some impact on magnitude of movement in Pakistan, overall
412 movement will likely remain aligned with pre-COVID-19 patterns.

413 This work highlights the substantial population movement that occurs both within Pakistan and across
414 the border with Afghanistan, particularly at Torkham border. Ensuring the NEAP incorporates
415 strategies to specifically target these groups, locations and modes of travel is critical to consistently
416 reaching HRMPs and ultimately ensuring eradication of WPV1 from this epidemiological block.

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421 **References**

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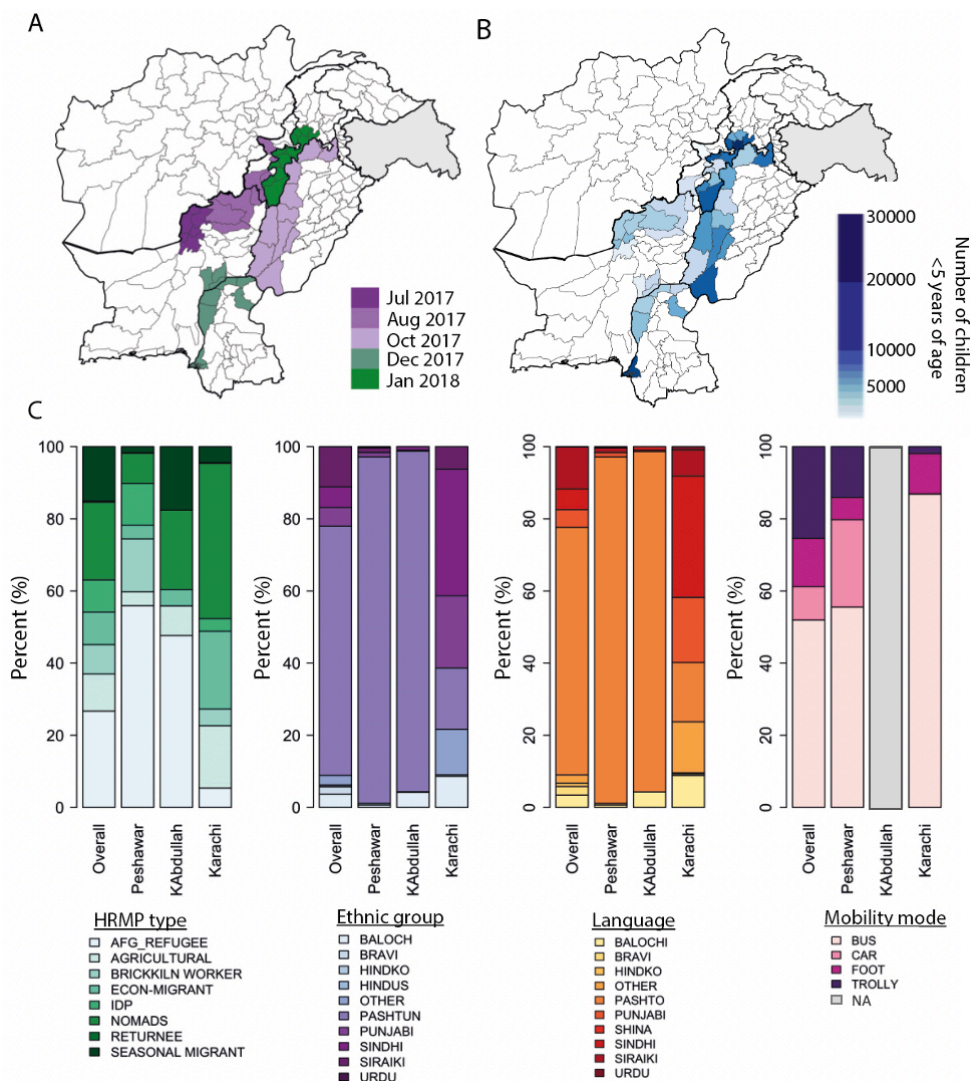
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491 **Figures**

492

493 **Fig 1:** High-risk and mobile population (HRMP) assessments 2017-2018. (A) Location and timing of
 494 HRMP assessments. Colours indicate the month and round of assessment. Purple and green shading
 495 indicate round 1 and 2, respectively. (B) Number of children <5 years of age assessed in each district.
 496 (C) Demographic information of assessed children, including HRMP type, ethnic group, language and
 497 mobility means.
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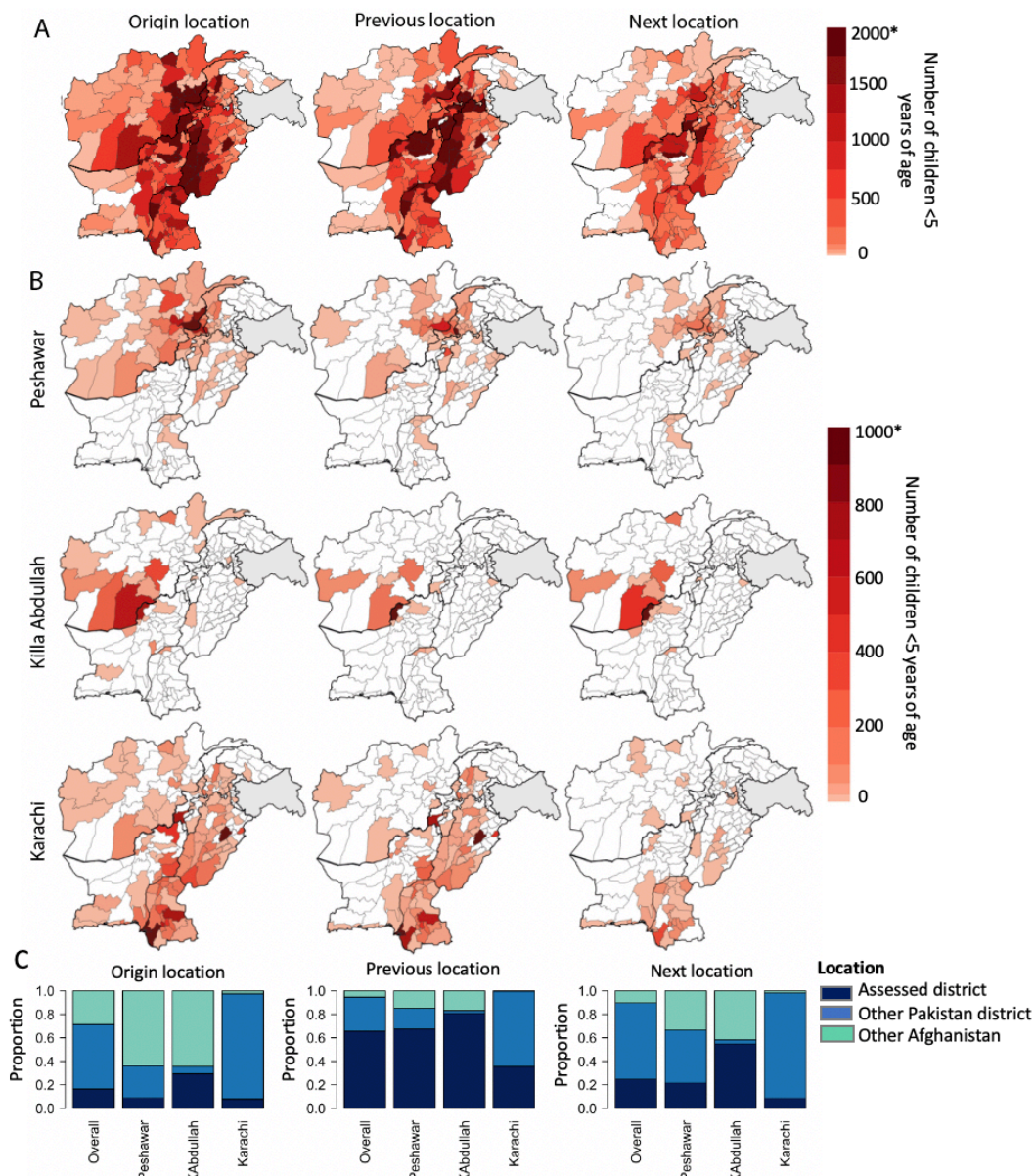


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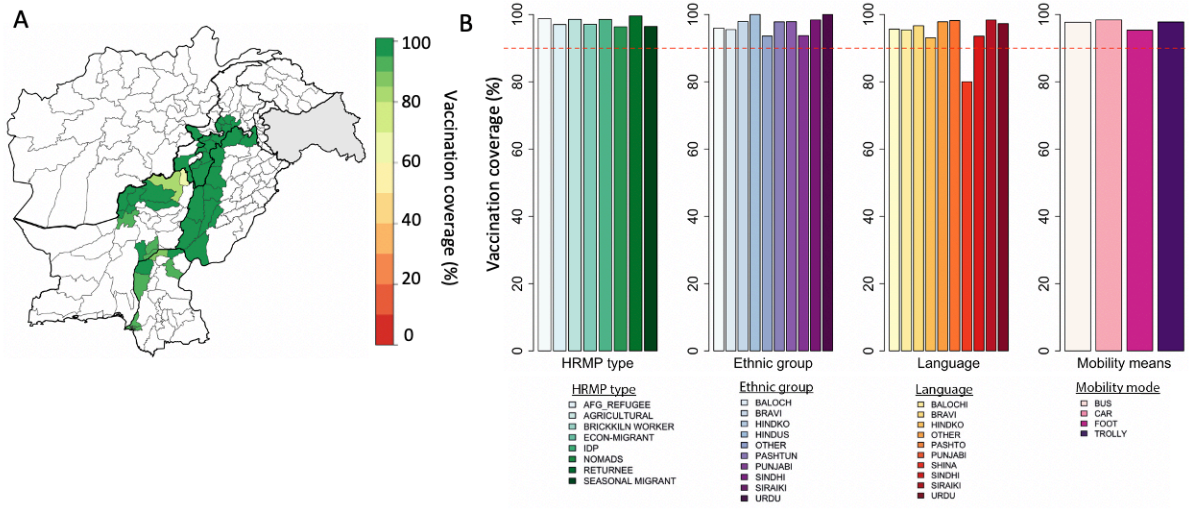
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502 **Fig 2:** Movement patterns of HRMP children <5 years of age, including reported origin, previous and
 503 next location of assessed children. (A) Overall origin, previous and next location of all HRMP children
 504 assessed. (B) Origin, previous and next location of children assessed in Peshawar, Killa Abdullah and
 505 Karachi. (C) Proportion of total assessed children reporting origin, previous and next locations as their
 506 current location (i.e. location of assessment).
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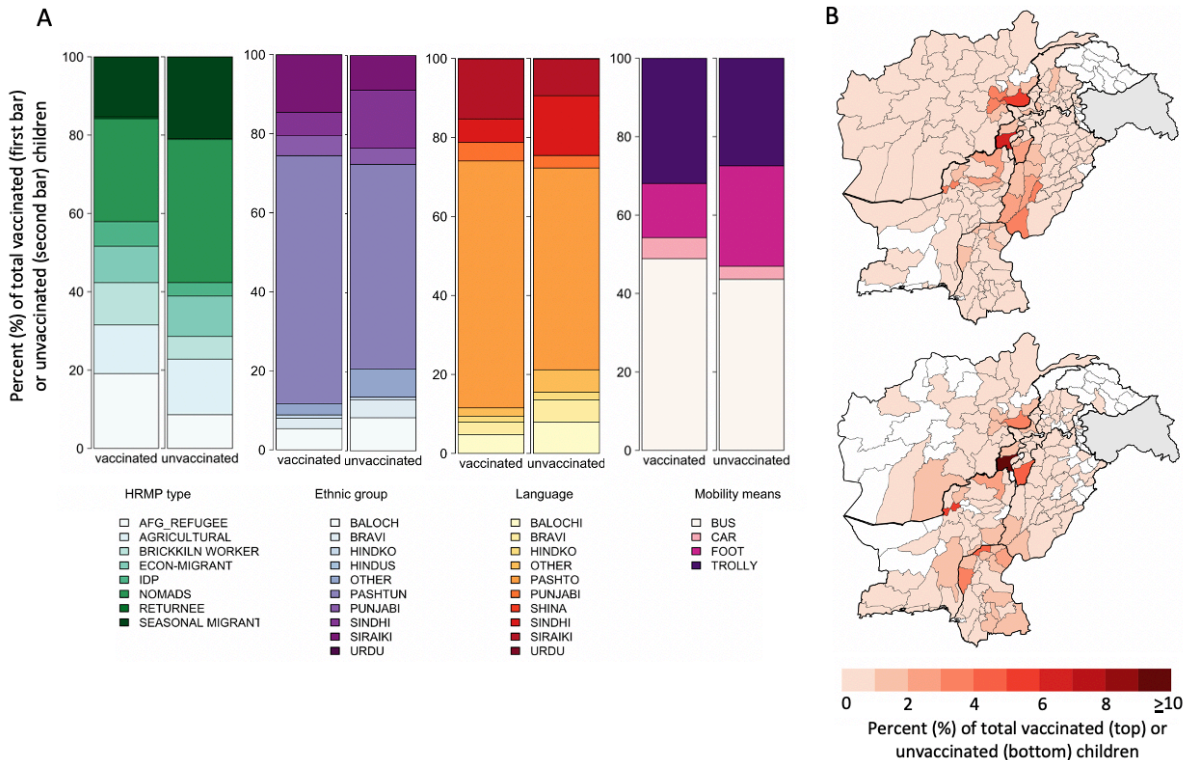


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511 **Fig 3:** Vaccination coverage of assessed HRMP children <5 years of age based on most recent SIA. (A)
 512 Vaccination coverage of HRMP children assessed based on their assessed location. (B) Vaccination
 513 coverage of children assessed based on HRMP type, ethnic group, language and mobility means.



514 **Fig 4.** Demographics and origin location of vaccinated versus unvaccinated children. (A) Percent of
 515 total vaccinated (first bar) or unvaccinated children (second bar) by demographic information,
 516 including HRMP type, ethnic group, language and mobility means. (B) Percent of total vaccinated (top
 517 map) or unvaccinated children (bottom map) by origin location.



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