BMJ Open

Maximising access to timely trauma care across population of Karachi and its districts: a geospatial approach to develop a trauma care network

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To cite: Ashraf MN, Khalil MS, Akhtar A, *et al*. Maximising access to timely trauma care across population of Karachi and its districts: a geospatial approach to develop a trauma care network. *BMJ Open* 2022;**12**:e051725. doi:10.1136/bmjopen-2021-051725

► Prepublication history and additional supplemental material for this paper are available online. To view these files, please visit the journal online (http://dx.doi.org/10.1136/bmjopen-2021-051725).

Received 31 March 2021
Accepted 07 March 2022

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ABSTRACT

Objectives To develop and propose a cost-effective trauma care network for Karachi, Pakistan, by calculating maximum timely trauma care (TTC) coverage achieved with the addition of potential designated private and public level 1 and level 2 trauma centres (TCs).

Setting A lower middle-income country metropolis, Karachi is Pakistan's largest city with a population of 16 million and a total of 56 hospitals as per government registry data.

Participants 41 potential TCs selected using a two-level, contextually-relevant TC designation criteria adapted from various international guidelines.

Primary and secondary outcome measures Maximum TTC coverage achievable with the addition of potential TCs. Proposed trauma care network composition to achieve maximum TTC coverage.

Results Coverage with five public level 1 hospitals alone is 74.4%. Marginal benefit with stepwise addition of five potential private level 1 TCs, four public level 2 TCs and two private level 2 TCs is 12.2%, 7.1% and 3.1%, respectively. Maximum possible TTC coverage is 96.7%. Poorest coverage with the proposed 16 hospital network is noted in Malir district while 100% coverage is achieved in the centrally located South, Central and East districts.

Conclusion Addition of private level 1 and private and public level 2 hospitals to the trauma care network is necessary. Implementation of the proposed trauma care network requires strong stewardship from the government and coordinated effort of multiple stakeholders is needed to ensure standard TC designation. The study exhibits an effective method to scientifically plan and develop a cost-effective trauma system which can be applied in other resource-limited geographical areas.

Strengths and limitations of this study

- We used Google Maps API (Application Programming Interface) to accurately identify 30 min hospital catchment areas based on updated travel speeds and road networks.
- Population distribution from the Pakistan Bureau of Statistics census was not available but we used gridded population data to get a fair estimate of population distribution.
- We classified facilities based on online information since we could not visit each facility due to resource limitation.

INTRODUCTION

Trauma is the sixth and seventh leading cause of death and disability, respectively, around the world.[1] In 2019, injuries resulted in the loss of 249 million disability-associated life years (DALYs) and 4.2 million deaths. As many as 5.7% of all deaths in Pakistan during 2019 were due to injuries, while among the 15–49 years age group, 16.6% of deaths and 13.6% of DALYs were attributed to injuries.[1] In Karachi, data collected by the first Road Traffic Injury Surveillance project recorded 1021 deaths in 2015 from three major hospitals of the city, with 85.3% of them being men and 28% in the 21–30 year age group.[2]

Studies from developed countries suggest better trauma survival can be achieved by improving on-scene stabilisation.[3 4] However, this requires significant investment in specialised resources and personnel who can reach and deliver state-of-the-art care at the site of an injury. Fortunately, other studies indicate that there is a survival benefit from overall shorter prehospital time (PHT).[5–10] This is true especially in areas without a formal prehospital care, and in cases of severely injured patients, patients with traumatic brain injury, penetrating injuries and injured patients with hypotension.[7–10]

Access to TTC therefore has been a metric used even in developed countries to evaluate the effectiveness of trauma systems. Determined by the geographical spread of the designated and verified facilities, Branas *et al* found that 84.1% of the US population,[11] and Hameed *et al* found 77.5% of the population in Canada[12] had 60 min access to level

Table 1 District information

Districts	Area (km^2)	Population	Population density (people per km^2)	Grid cells
Karachi Central	69.2	2 972 639	42 956.3	114
Karachi East	103.2	2 909 921	28 197.0	170
Karachi South	121.7	1 791 751	14 719.8	221
Karachi West	532.1	2 008 901	3775.5	966
Korangi	126.5	3 914 757	30 936.4	213
Malir	3117.7	2 457 019	788.1	5350
Overall	4070.5	16 054 988	3944.3	7034

1–2 TCs, while Lilley *et al* found 84.6% of New Zealand's population had a 60 min access to advanced level TCs.[13] The access coverage was particularly poor for those residing in rural or peri-urban areas and consisted mainly of marginalised populations.

Karachi is located on the southern coastal belt of the Sindh province of Pakistan. It is inhabited by 16 million people and is classified among the top 10 fastest growing cities in the world.[14 15] Achievement of widespread and equitable access to timely trauma care (TTC) should be an important target for a city like Karachi where the trauma systems are still under development. To achieve equitable and widespread TTC access across Karachi, a network of hospitals would be needed. Ideally, existing resources and institutions should be used, requiring a mix of public and private sector facilities to ensure adequate coverage of the city. Using a geographic information system (GIS) modelling approach, we conducted this study to identify hospitals that could provide the required coverage network.

METHODS

The city of Karachi is divided into six districts spread over 4000 km^2 (table 1). Shape-files for Karachi districts were obtained from the Humanitarian Data Exchange website.[16] A tessellation and clipping function combination was used to obtain a 500 m by 500 m cell grid that spanned Karachi, leading to a total of 7034 cells. Each cell was used as a basic unit of analysis and was attributed to its district, with a population density being calculated using Landscan 2018 population density raster data and kernel density function.[17] Grid shape-file data were exported to spreadsheets for further processing. The population count for each cell was then calculated by district population after applying weights for each cell's population density relative to other cells in the district.

Facility data

Sindh Rescue Medical Services facility registry (attached as online supplemental annex 1) and online search was done to consolidate a complete list of facilities. College of Physicians and Surgeons Pakistan website and other sources were used to collect information on the facilities' bed strength, range of surgical services and academic accreditation for general surgery and neurosurgery training.[18] As the project did not include any human or animal subjects, it was exempt from ethical approval.

Defining TC levels

We referred to well-defined guidelines such as the American Trauma Society, Trauma Association of Canada and WHO guidelines[12 19 20] to propose a contextually relevant, two-level TC designation criteria for Karachi. Based on this we defined our selection criteria for potential level 1 and level 2 TCs (table 2).

Potential level 1 TCs

Public sector tertiary level hospital or a private sector hospital with the following:

- Availability of orthopaedic surgery, neurosurgery, anaesthesiology, emergency medicine, radiology and critical care
- Continuing education for staff, and accredited for general surgery training
- Bed strength of more than 200 beds.

Potential level 2 TCs

A public sector secondary level hospital or a private hospital with the following:

- Trauma nurse(s) and physicians available on patient arrival.
- Bed strength of more than 100 beds.

Defining TTC

The definition of TTC can vary. We define it as access to a trauma centre (TC) within 30 min of travel time based on previous studies on average PHT and effect on outcomes in high-income countries.[21 22] Cells lying within 30 min travel time of any of the potential TC hospitals were categorised as covered for TTC. A JavaScript code (online supplemental annex 2) on Google scripts using the Google Maps Routes directions API (Application Programming Interface) was used to measure the travel times between hospitals location and the central geocoordinate (centroids) of the grid cells. A radius of at least 12.5 km was used to encompass all cells within the 30 min travel time and confirmed by the visualisation in QGIS. The travel time reported by Google Maps API was the average of the travelling times noted throughout the day.

Modelling

Using data for the grid cells on access to various hospitals, models were constructed to measure percentage population coverage that can be achieved by a list of hospitals. A baseline model was constructed to measure the percentage population TTC coverage possible through

Table 2 Proposed criteria for TC designation and potential candidate hospitals

Level	Proposed criteria	Rationale	Criteria for potential candidates
1	**24-hour** immediate coverage by general surgeons, as well as coverage by the specialties of orthopaedic surgery, neurosurgery, anaesthesiology, emergency medicine, radiology and critical care. **May** have cardiac surgery, haemodialysis and microvascular surgery services. **Leadership** in prevention, public education to surrounding communities. **Referral** resource for communities. **Comprehensive** quality assessment programme. **Continuing** education for staff. **Prevention** programme for staff. **Meets** annual volume of severely injured patients; bed capacity more than 200 beds. **Equipment, skills and knowledge capacity** as per Guidelines for Essential Trauma Care (GETC) for tertiary specialist hospital.	Similar to the level 2 and 3 TCs according to the 'American Trauma Society' (ATS). Level 1 of ATS not possible in our setting, no 24-hour in-house general surgeon coverage due to the limited workforce. Similar to level 1 and 2 according to 'Trauma Association of Canada' (TAC). Similar to the 'Tertiary and Specialist Hospital' level according to the GETC.	Availability of orthopaedic surgery, neurosurgery, anaesthesiology, emergency medicine, radiology and critical care. Continuing education for staff, and accredited for general surgery training. Bed strength of more than 200 beds.
2	**Trauma** nurse(s) and physicians available on patient arrival. **Capacity** to implement ATLS protocols. **May** provide surgery and critical-care services if available. **Transfer** protocols for patients requiring more comprehensive care. **Bypass and triage protocols** are in place diverting major trauma patients to level 1 and 2 centres. **Comprehensive** quality assessment programme. **Prevention** efforts and outreach programme. **Located** in areas not served by a level 1 TC. **Meets** certain patient volume; bed capacity more than 100 beds. **Equipment, skills and knowledge capacity** as per GETC for GP and basic level hospitals.	Similar to the level 4 and 5 TCs of ATS. Similar to level 3, 4 and 5 TCs of TAC. Similar to the GP-level and basic-level hospitals according to GETC.	Trauma nurse(s) and physicians available on patient arrival. Bed strength of more than 100 beds.

ATLS, Advanced Trauma Life Support; GP, General practictioner; TC, trauma centre.

public sector potential level 1 TCs. Three stepwise models were further constructed to try and develop an adequate coverage model. In the first of these models, potential private level 1 TCs that provided benefits were included. In the second and third, public level 2 and private level 2 were added respectively. In each model, sequential addition of hospitals was automated and done through Stata using a loop code that identified the TC with highest incremental coverage benefit in each category. Multiple iterations of the loop were run until all TCs were exhausted. Any hospital that did not provide incremental coverage benefit was considered to have overlapping 30 mi catchment area of already selected hospitals, and was not added to the proposed model.

Data visualisation

Data processed in Stata was linked to the grid shapefile in QGIS to visualise the coverage provided by each coverage model.

Patient and public involvement

There was no involvement of the public or the patients in the design, conduct or reporting of the study. However, educating the government and non-governmental stakeholders about our findings and proposed strategy is a core element of our dissemination plan.

RESULTS

Overview of potential TCs

We compiled a list of 54 hospitals. Forty-one hospitals out of these qualified our criteria for potential TCs, of which 5 were categorised as public level 1 TCs, 10 as private level 1 TCs, 8 as public level 2 TCs and 18 as private level 2 TCs (figure 1). Fifteen of the 41 hospitals are located in the South district, while Malir and West districts have only 3 hospitals per district (table 3). The disparity in hospital

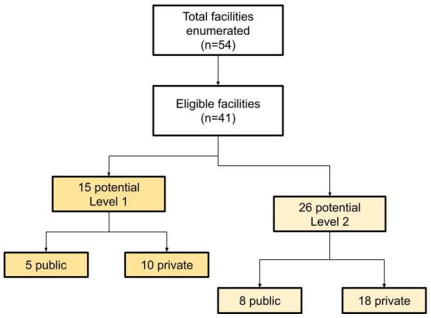

Figure 1 Flow diagram for facility selection and categorisation.

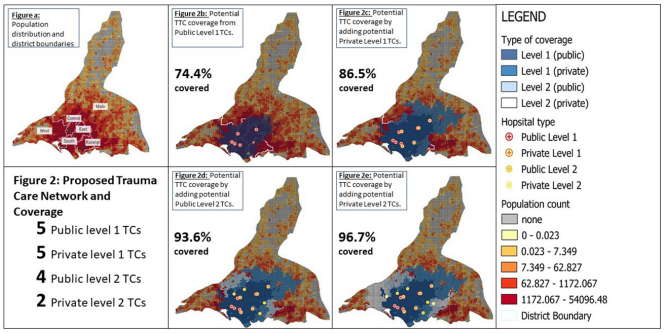

Figure 2 Proposed trauma care network and coverage. TCs, trauma centres; TTC, timely trauma care.

density between the districts is reflected in the TTC coverage analysis.

Baseline model—coverage by public level 1 TCs

The five potential public level 1 TCs identified provide potential TTC coverage to up to 74.4% of Karachi's population (figure 2 and table 4). However, there is a stark inequity in potential TTC coverage across districts; the potential coverage by these hospitals in South, Central and East districts is as high as 99.8%, 99.6% and 90.1%, respectively, but as low as 33.9%, 42.3% and 73.3% in Malir, Korangi and West districts, respectively (table 4).

Model 1—coverage benefit of adding private level 1 TCs

Sequential addition of the 10 potential private level 1 TCs shows an increase in coverage until the fifth hospital after which increase in coverage saturates to zero (figure 3). The five hospitals that increase coverage in order of marginal benefit include Jinnah Medical College Hospital located in Korangi district, Ziauddin

Table 3 Potential public and private level 1 and level 2 TCs and their districts from all over Karachi

District-wise hospital count:
Karachi South—15 hospitals, Karachi Central—8 hospitals, Karachi West—4 hospitals.
Karachi East—6 hospitals, Korangi—6 hospitals, Malir—two hospitals.

	Potential public level 1 TCs	Potential private level 1 TCs	Potential public level 2 TCs	Potential private level 2 TCs
Maximise coverage	► Abbasi Shaheed Hospital ► Jinnah Postgraduate Medical Center ► Dow University Hospital—Ojha Campus ► Civil Hospital and Trauma Center ► Lyari General Hospital	► Jinnah Medical College Hospital—Korangi ► Ziauddin Hospital—North Nazimabad Campus ► Baqai University Hospital—Highway ► Memon Medical Institute ► Pakistan Naval Society—Shifa Hospital	► Sindh Government Hospital—New Karachi ► Sindh Government Hospital—Korangi ► Sindh Government Hospital—Saudabad ► Sindh Government Qatar Hospital—Orangi Town	► Al Tibri Medical College ► Murshid Hospital and Healthcare Centre
Do not maximise coverage		► Ziauddin Hospital—Clifton Campus ► Hamdard University Hospital ► Medicare Hospital ► Liaqat National Hospital ► Aga Khan University	► Sindh Government Children's Hospital North ► Sindh Government Hospital Liaqatabad ► Sindh Government Services Hospital ► Sindh Government Hospital Ibraheem Hyderi	► National Medical Center ► Altamash Hospital ► South City Hospital ► OMI Hospital ► Kutiyana Memon Hospital ► Saifee Trust Hospital ► Baqai University Hospital—Nazimabad ► Mamji Hospital Orthopedic and General ► Holy Family Hospital ► Karachi Adventist Hospital ► Chiniot General Hospital ► The Indus Hospital ► Creek General Hospital ► Patel Hospital ► Darul-Sehat Hospital ► Ziauddin Hospital—Kemari Campus

TCs, trauma centres.

Table 4 Maximum possible coverage and marginal benefit achieved in coverage overall and across districts by adding hospitals to the network

		Five public level 1 TCs	Adding five private level 1 TCs	Adding four public level 2 TCs	Adding two private level 2 TCs
Karachi Central population=2 972 639	Covered (count)	2 701 378	2 972 639		
	Coverage(%)	90.9%	***100.0%***		
	Benefit (%)		9.1%		
Karachi East population=2 909 921	Covered (count)	2 897 611	2 909 921		
	Coverage(%)	99.6%	***100.0%***		
	Benefit (%)		0.4%		
Karachi South population=1 791 751	Covered (count)	1 787 289	1 791 751		
	Coverage(%)	99.8%	***100.0%***		
	Benefit (%)		0.2%		
Karachi West population=3 914 646	Covered (count)	2 869 590	2 933 655	3 413 714	3 860 025
	Coverage(%)	73.3%	74.9%	87.2%	***98.6%***
	Benefit (%)		1.6%	12.3%	11.4%
Korangi population=2 008 901	Covered (count)	850 322	1 840 321	1 998 840	1 998 840
	Coverage(%)	42.3%	91.6%	99.5%	***99.5%***
	Benefit (%)		49.3%	7.9%	0.0%
Malir population=2 457 019	Covered (count)	832 491	1 442 752	1 941 703	1 988 493
	Coverage(%)	33.9%	58.7%	79.0%	***80.9%***
	Benefit (%)		24.8%	20.3%	1.9%
Overall population=16 054 877	**Covered (count)**	11 938 680	13 891 039	15 028 568	15 521 669
	Coverage(%)	**74.4%**	**86.5%**	**93.6%**	***96.7%***
	Benefit (%)		**12.2%**	**7.1%**	**3.1%**

Bold values signify when saturation was acheived in the coverage and adding more hospitals to the model did not provide any marginal benefit.

Hospital-North Nazimabad located in Central district, Baqai Medical University located in Malir district, Memon Medical Institute in East district and PNS Shifa Hospital in South district. The remaining five hospitals overlap in coverage areas with the public level 1 TCs and selected private level 1 TCs providing no additional benefit in coverage.

Addition of private level 1 increases coverage to a maximum of 86.5% overall (figure 2 and table 4). The addition achieves complete potential coverage in South, Central and East districts. Coverage also improves drastically in the Korangi district from 42.3% to 91.6%. However, potential TTC coverage in Malir and West districts remains poor (58.7% and 74.9%, respectively).

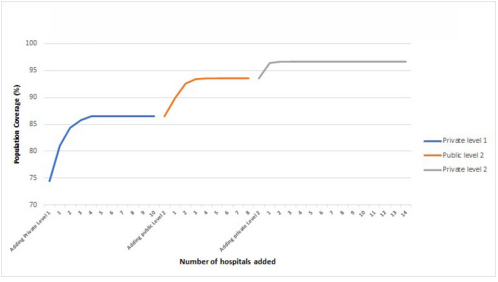

Figure 3 Increase in population coverage by adding in potential private level 1, public level 2 and private level 2 TCs to the network. TCs, trauma centres.

Model 2 and 3—coverage benefit of adding level 2 TCs

Sequential addition of the eight potential public levels 2 TCs showed an increase in coverage until the addition of the fourth hospital after which the increase in coverage saturated to zero (figure 3). These four hospitals include Sindh government hospitals in New Karachi, Korangi and Saudabad areas of Central, Korangi and Malir districts, respectively, and Qatar Hospital located in West district. Subsequent sequential addition of the 18 potential private level 2 TCs showed an increase in coverage until the second hospital (figure 3). These include the Al Tibri Hospital in Malir and Murshid Hospital and Healthcare Center in the West district.

The maximum possible potential coverage by adding the level 2 TCs to the network is 96.7% of Karachi's population (figure 2 and table 4). The maximum coverage in Malir reaches up to 80.9%, while coverage in Korangi

and West district reach up to 99.5% and 98.6%, almost reaching completion.

Proposed hospitals for the network

From the list of 41 potential TCs, we require 16 TCs to provide the maximum possible TTC coverage in Karachi (table 3). Figure 2 shows a visual representation of the baseline coverage with only the public level 1 TCs (figure 2B), and the incremental coverage by adding in the private level 1 TCs (figure 2C), public level 2 TCs (figure 2D) and private level 2 TCs (figure 2E).

DISCUSSION

Currently, no official trauma care network exists in Karachi. There is no defined protocol for the selection of hospitals to which a trauma patient should be taken. By officially designating level 1 and level 2 TCs across various areas, such protocols can be developed and implemented. Consequently, this can improve the process of timely patient transfer which is often key in the survival of patients with severe injuries. Our study provides a list of 16 hospitals that should be included in the trauma care network that will provide TTC coverage to as much as 96.7% of Karachi's population.

It should be clear from our results that the five public tertiary care hospitals in themselves are not able to provide TTC coverage to the population of Karachi, especially in the periurban areas of Korangi, West and Malir districts. The inclusion of five private level 1 hospitals enhances the overall coverage by more than 10% and increases coverage by as much as 49.3% in the Korangi district. The addition of these hospitals into the network is therefore important.

However, even after the addition of private level 1 TCs, TTC coverage is achieved for only 86.5% of the population in Karachi. In districts like Malir, West and Korangi, level 1 TCs fail to cover up to 41.3%, 15.1% and 8.4% of the population, respectively. Inclusion of the potential level 2 TCs is therefore important as well; our analysis shows the addition of six facilities will provide coverage benefits of 22.2.%, 23.7% and 7.9% in Malir, West and Korangi districts, respectively.

The potential 96.7% coverage by the proposed network is similar to the realised coverage in the USA, Canada and New Zealand.[11–13] However, unlike these other countries, Karachi's trauma system lacks the efficient prehospital services established in these countries and certain steps have to be taken to actualise the potential coverage in Karachi postulated by our study.

As a first step, there is a need for strong stewardship and dedicated commitment from all the stakeholders required for establishing the trauma care network. Guidelines for TC accreditation need to be decided. Our paper has proposed guidelines that are locally relevant and based on established guidelines in other countries. A separate study shows that there is a great variation in the standard of services at hospitals in Karachi. There is a need to ensure minimum standards of service delivery in the 16 potential TCs identified for the network. Lastly, keeping in mind Karachi's fast-growing population, there is a need to build new hospitals, especially in the peri-urban districts of Karachi.

Some limitations in our approach were as follows. Ideally, population distribution from the Pakistan Bureau of Statistics (PBS) census should have been used but was not available for public use. However, the use of gridded population density maps is a reliable alternative and has been used previously for research purposes.[23] We used information from websites to classify hospitals as potential TCs. The validity of this information could be more concrete through on-site assessment of these facilities. We also used the best average of travel times based on historical data and were unable to comment on population coverage variation with season and traffic. Our future work will focus on identifying population coverage variation with different time cut-offs.

Our approach was unique in how we used Google Maps API to measure 30 min hospital catchment areas. While this study served as an excellent planning exercise for Karachi's trauma system, it validates an effective method to scientifically plan and develop a cost-effective trauma system which can be applied in other resource-limited geographical areas. This method has an advantage over the conventional network analysis methodology as it is based on accurate and updated travel speeds and road networks.[24] Rather than measuring possible coverage for all hospitals, we identified hospitals that provide maximum coverage with minimal overlap. This provides feasible, cost-effective and actionable recommendations for the development of the trauma network.

Contributors MNA, MSK and AA worked on the conception and design of the study. The acquisition of data were handled by MSK and MNA while the data were analysed and interpreted by MNA, AA, LS and AL. The manuscript was drafted by MSK, MNA, LS and AL and all authors were involved in the critical revision of the manuscript. The study was carried out under the supervision of LS along with AS who is also the guarantor of this study.

Funding The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.

Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not applicable.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available upon reasonable request. The data from the study has been published with the paper and Javascript codes to calculate travel times have been submitted as Annex 2. Additional material including Stata files used for the analysis can be made available on request from the first author nabeelashraf@live.com.

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