



Hierarchical Healthcare Facility Location at the Subdistrict Level in Western Uttar Pradesh: A Heuristic Approach

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ABSTRACT

The Governments across the world are making continuous efforts to attain health for all. The efforts can gain more efficiency if the new healthcare facilities are created at optimal locations. There are various constraints on healthcare facilities, like cost of setup, coverage distance, service distance, population load, manpower and services offered. These constraints operate in a complex setting giving rise to alternate scenarios. The study proposes replicable heuristics to obtain the optimal locations under alternate scenarios for the Sub Centers (SC), Primary healthcare centers (PHC) and Community healthcare centers (CHC). The study takes the case of a block of villages in most populous state of India using the publicly available data, data from census, government portals and Bing Maps services. The study generates several alternatives scenarios for maximize demand, minimize service distance and minimize total costs for different population covered and service distance. The methodology suggested here might be helpful for the location decision making at the block level by the district administration.

Keywords: Heuristics, Optimal location planning, healthcare for all, Bing maps.

INTRODUCTION

The Governments across the world are making continuous efforts to attain health for all. The Government of India (GOI) has seven decades of continuous efforts towards the protecting and promoting the aim of health for all. The efforts can be traced through the steps of 'The Declaration of Alma-Ata' in September 1978 and through various National Health Policies (NHP)- NHP 1983, NHP 2002 and NHP 2017. The aim of latest NHP 2017 states "attainment of the highest possible level of health and well-being for all at all ages, through a preventive and promotive healthcare orientation in all developmental policies, and universal access to good quality healthcare services without anyone having to face financial hardship as a consequence. This would be achieved through increasing access, improving quality and lowering the cost of healthcare delivery" [1] One of the deliverables in the NHP is increasing access of healthcare facilities, which can be achieved through building new facilities in a planned manner preferring the optimal locations.

The study proposes a data-driven approach through the case in a block of villages in Uttar Pradesh, the most populous state in India. Using publicly available data from web applications, census data, the optimal locations of the healthcare facilities are identified and presented in the geographical map of the district.

The paper is structured as follows: a review of the literature discussing the health ecosystem in the state of Uttar Pradesh to identify the deficiency of State's healthcare facilities and the criteria of location selection. The methods of location planning are presented in Section 2. The solution methodology is presented in Section 3, followed by Section 4, detailing the results and discussions and its managerial.

REVIEW OF LITERATURE AND BACKGROUND OF THE STUDY

The following sections will discuss the important points of policy for health infrastructure, current status of health facilities available to the population as of the year 2018 and the methods of optimal location planning.

Health Policy

The GOI defined rural healthcare system in India consists of Sub Centers (SC), Primary Healthcare Centers (PHC) and Community Healthcare Centers (CHC). The PHCs are the most important part of rural healthcare. In order to bring about behavioral change and include services in relation to maternal and child wellbeing, family protection, education, immunization, diarrhea prevention and control of communicable disease programs, The SCs are assigned tasks relating to interpersonal communication. Under the Minimum Needs Program (MNP)/ Basic Minimum Services (BMS) Programme, the PHCs are developed and maintained by the State Governments. It operates as a referral unit for 6 SCs and has 4-6 patient beds. Under the MNP/BMS programme, CHCs are developed and maintained by the state government. Four medical specialists, i.e. surgeon, psychiatrist, gynaecologist and pediatrician, assisted by 21 paramedical and other personnel, must be staffed by a CHC. With one Operation Theater (OT), X-ray, labour room and laboratory equipment, it has 30 in-door beds. It functions as a referral center for 4 PHCs and also offers obstetric care and specialist consultation services [1]. The Government of India's population norm are different for Plains and Hilly/ Tribal/ Difficult areas. SC covers 5000 and 3000, PHC covers 30,000 and 20,000 and CHC covers 120,000 and 80,000 population respectively [2].

Health Infrastructure

The state Uttar Pradesh has 75 Districts, 106704 Villages. About 96.86% of the total area is rural and 77.7% of the population lives in rural areas. As per census 2011, the state has a population of 19,98,12,341 with 15,53,17,278 living in rural areas. The percentage of total population growth in the decade (2001-2011) is 20.23% (rural 17.97% and urban 28.82%) and population density (per sq.km) is of 829 persons (rural 666, urban 5884). The number of SC, PHC and CHC in Uttar Pradesh witness a significant shortfall, that can be seen from the Table 2. Apart from the available infrastructure UP also has 171 District Hospitals (DH) and 133 Mobile Medical Units (MMU) but no sub-divisional hospitals.

Location Models

The exact location of facilities is critical in healthcare. The repercussions of bad location decisions extend far beyond cost and customer service in healthcare. If too few facilities are used and/or if they are not well placed, it may lead to a rise in population mortality and morbidity. Thus, the facility location modelling is of far more importance when applied to the setting of healthcare facilities in reality.

In the domain of Operations Research, there are many models for location planning. These models help in location planning through various considerations like cost and benefits, the size, the geographic area, transportation costs and others. The healthcare and related location literature can be classified in three broad areas: accessibility models, adaptability models and availability models [3]. The accessibility is the ability of patients to reach the healthcare facility. Accessibility-based models are static models and ignore the needs of the system to evolve in response to changing conditions as well as short-term fluctuations in the availability of service providers. Adaptability models often consider multiple scenarios and try to find good compromise solutions. Availability models focus on the short-term balance between the ever-changing demand for services and the supply of those services [3]. The facility location models considered classic are: The P-median model, the covering model and the center model [4]. These models optimize on the distance from clients to their closest facility [5].

The P-median model with added constraints on travel time to hospitals and penalties for overutilization been used by researchers for facility location [6]. Researchers also have used capacitated P-median model to optimize the collection, testing and distribution of blood products [7]. Daskin (2004) observes that "... while heuristic decomposition approach may make intuitive sense, it is not guaranteed to result in an optimal solution". The objective function of the set covering problem minimizes the total fixed cost of facilities at selected candidate sites. The constraint set states that the total number of facilities covering the demand node i . Demand node (for all villages) must be covered by at least one of the selected candidate site j (X_j is 1 for that site). Location set covering models are used when the decision-maker is interested in focusing on operating cost of the facilities as they are the dominant portion of the total cost (in a healthcare setting). This is achieved by minimizing the number of facilities that are located. Practical issues of set covering model are that it results in solutions with a prohibitive cost to achieve the constraint of covering all demand. Location set covering model often results into a large number of facilities required. If a model can consider the distinction between nodes generating high vs. low demand; the decision-maker can choose to prefer the high demand centres. This is covered in the maximal covering model [8]. In this model, the objective function maximizes the number of covered demands (not simply the nodes). The constraint set states that demand node i cannot be counted as covered unless we locate at least one facility that is able to cover the demand node. Also, the constraint states that the number of facilities shall be a minimum P . Daskin (2004) suggests Lagrangian relaxation for solving this problem effectively.

The center of a gravity model was used by relatively fewer researchers in the domain of healthcare. These studies used distance as the measure of separation. It is also been used to identify service areas of hospitals [9,10,11,12]. One of the studies used gravity models to study the effects of hospital closure [13] and physician office location [14] on patient flow in hospital service in the USA, another to locate blood bank clinic in Quebec [15].

The Hierarchical models allow solving for a number of different services (like- sub-centres, primary health centres and community health centres) simultaneously. In the hierarchical models (generally), the lower-level facilities are assigned lower weight and higher-ordered facilities a higher weight. The model requires at least three factors to be considered. The *first factor* is the level m facility. The *second factor* is if the level m facility is successively inclusive type then, is it providing all services (cumulative set of services) to all the demand nodes, or only to those demand nodes where the infrastructure for those services exist. The *third factor* is whether the higher-level facility is nested with a lower-level facility or not.

In the table below we present a few of the selected research work done in the area of location planning in the health care facilities. However, these models have a limited scope for application in the context of location decisions in a developing country setup.

Table 1: Table of selected work in location planning of healthcare facilities

Optimum allocation of services	Morrill, R. L., & Kelley, P. (1969) [16]
Assessing the locational efficiency of a system of hospitals	Vitaliano, D. F. (1988) [17]
Ambulance location optimization.	McAlee & Naqvi, 1994, Ball & Lin, 1993 [18]
Integrated GIS and location-allocation approach to public facilities planning	Yeh, A. G. O., & Chow, M. H. (1996) [19]
Modeling framework for hospital location and service allocation	Chu, S. C., & Chu, L. (2000) [20]
Optimization of community health center locations and service offerings with statistical need estimation	Griffin, P. M., Scherrer, C. R., & Swann, J. L. (2008) [21]
Optimization of preventive health care facility locations. Emergency medical services	Gu, W., Wang, X., & McGregor, S. E. (2010) Pirkul & Schilling, 1988 [5]
Organizing hospitals into networks: a hierarchical and multiservice model to define location, supply and referrals in planned hospital systems	Mestre, A. M., Oliveira, M. D., & Barbosa-Póvoa, A. (2012) [22]
The impact of client choice on preventive healthcare facility network design	Zhang, Y., Berman, O., & Verter, V. (2012) [23]

RESEARCH METHODOLOGY

Selection of the Block:

Based on data compiled from the Uttar Pradesh Human Development Report (UPHDR) 2008, rankings of the districts can be done on the Gender Development Index (GDI) and Human Development Index (HDI) [24]. Using this ranking the districts of Western UP can be divided into High, Medium and Low Category. The selected Tappal block for the study belong to the low category Aligarh district. The relative information of the deficiency of medical facility in Tappal is given in Table 3.

Location planning method:

The facilities shall be located in a way that they are both available and accessible for the intended use of services.

[25] Datta & Bandyopadhyay (1993) considered the mixed model approach to address micro-level planning in a hierarchical manner. The model proposed is most suitable for the current research since it addressed the region-specific constraints and developed the decision support system resulting in a descriptive model, capable of generating alternative scenarios under different socio-economic and environmental conditions. The model allowed decision-makers to evaluate the effect of alternative strategies to address regional planning objectives. The appropriateness of this work lies in the fact that, unlike other models developed in the western world which assumes the demand of facilities, the infrastructure (capital required, approach roads, electricity, and manpower) exist, this model first considered the facility submodule and then location submodule. The facility submodule generated alternative scenarios for the requirement of different types of the facility for a geographical region. The location submodule identified the optimal location (using modified capacitated location covering model) for the facility.

The whole process has two major steps 1) specifying the model and 2) solving the model. The modelling method required for this problem is a heuristic method to find a 'good' solution when the optimal solution cannot be obtained. Exact -optimal solutions are possible in the small problems which do not consider the various possible scenarios to the solution/constraint sets. The heuristic method makes a tradeoff between the quality of solution and computational complexity of the solution. The constraint set was created using the data available in the public domain to ascertain the cost of the facilities and distance of the health centre from the facilities. The capacity constraints on medical facilities were taken from health policies. To locate the facilities a period of ten years was considered. Since the study requires the model to satisfy most of the demand by locating fixed (minimum) of the facility subject to minimizing the distance to those facilities, optimization model for Maximal Covering Location Problem, the p-centre problem were used for this study.

DATA ANALYSIS

We have used a heuristic model similar to that of Datta & Bandyopadhyay, 1993, for capacitated maximal covering location (CMCL). Solver add-in of MS Excel is used for solving the model. The model is specified as below:

Notations

- V = $\{v_1, v_2, \dots, v_n\}$ = Set of the villages in a block.
- P = $\{p_1, p_2, \dots, p_n\}$ = Population of village v_i in the block.
- CAP = Capacity of the health facility.
- $C(v_i)$ = Set of villages which are at a distance less than specified 'd' from v_i .
- d_{ij} = Distance between villages i and j
- $C'(v_i)$ = The set of villages in ordered form as per the rank based on distance.
- $fc(v_i)$ = (facility cover) = Set of villages assigned to the health facility at village v_i
- p_{ij} = Population of village j assigned to facility at village i .
- $fc_p(v_i)$ = Total population covered under the serving area of a facility at village i .

t_i = Total travel time (in person km) for the facility at village i .

$IDX(v_i)$ = Index number of a village i based on distance and capacity (total population served). A smaller value of IDX is preferable.

Consider the set of n villages in the block $\{v_1, v_2, \dots, v_n\}$ having corresponding population $\{p_1, p_2, \dots, p_n\}$. The CAP i.e. capacity of health facility, can be estimated from the policy document of the Government of India with a tolerance limit of $\pm 10\%$ i.e. $CAP_{SC} = 5000 \pm 10\%$, $CAP_{PHC} = 30,000 \pm 10\%$ and $CAP_{CHC} = 1,20,000 \pm 10\%$ humans. The average cost of setting up the PHC is assumed to be INR 6.12 Lakhs (INR 0.612 Million) and CHC is INR 16.18 Lakhs [26]. For service distance and coverage distance we have assumed the average of UP as a reference value i.e. SC = 3 Km, PHC = 7.5 KM and CHC = 15 KM. The service distance limit is considered as (SC = 1.9Km, PHC = 4.53 KM and CHC = 10 KM) which is lower than the coverage distance limit considered as (SC = 2 Km, PHC = 5 KM and CHC = 10 KM.)

The inputs and choice alternatives to the location identification can be depicted through Figure 1. The algorithm requires the GIS locations and real travel time between the locations and dependent villages, the latitude and longitude of the villages were pulled using Google Maps [27] and distance between locations through Bing Maps. All the villages are identified through their numerical index and name, for example, 121695 'Fazilpur Kachh', the numeric index of village 'Fazilpur Kachh' is '121695' or '695'.

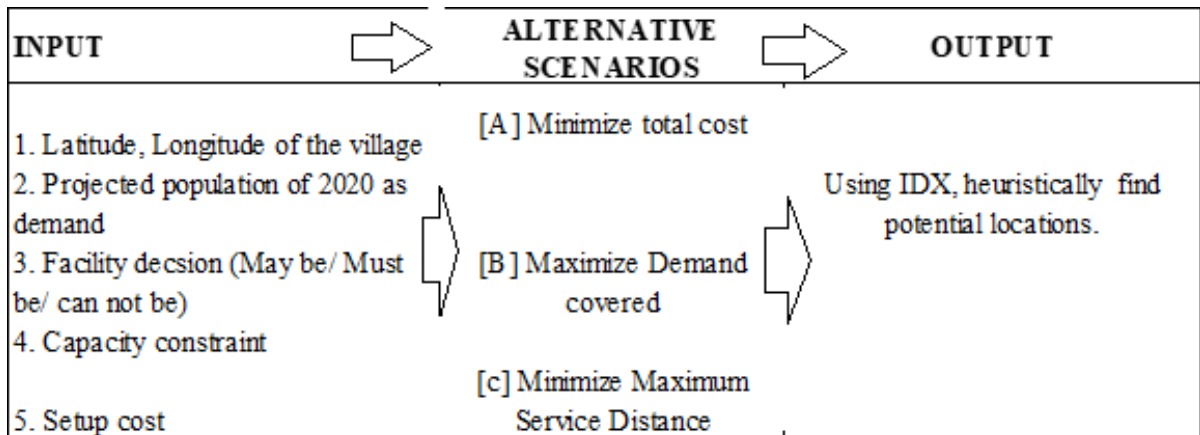


Figure 1 Health Location Model Input-Output

Solution Heuristics

The solution algorithm has the following five steps:

Step1: Let, there are k health facilities located at village i , therefore, the population which can be served by the k facilities will be $k * CAP$. If the population remaining to be served is r_i then,

$$p_i = k * CAP + r_i, \text{ where } 0 \leq k \leq CAP$$

Step 2: Identify the set of villages which are covered by the facility at v_i , $C(v_i)$, within a specified distance S_k (currently the minimum distance range recorded in the government data is 5 km), i.e.

$$C(v_i) = \{V_j \mid d_{ij} \leq S_k\} \dots \text{(distance criteria)}$$

Where, V_j is set of villages qualifying the criteria

On the basis of increasing distance or population, the set of villages can be ordered as $C'(v_i)$.

Step 3: (a) Identify, the subset of the ordered set $C'(v_i)$, to get the set of villages [denoted by $fc(v_i)$ = (facility cover)] assigned to the facility at v_i such that

$$\sum_{V_j \in C(v_i)} p_j \leq CAP \quad \text{Population within Capacity of facility (CAP)}$$

(b) if $\sum_{V_j \in C(v_i)} p_j > CAP$ i.e the location needs multiple facilities, find k such that

$$\sum_{j=1}^k p_j < CAP < \sum_{j=1}^{k+1} p_j \quad \forall V_j \in C'(v_i)$$

Where, for $1 \leq j \leq k$, $p_j = p_{ij}$ = population of v_j assigned to facility located at v_i
And,

$$p_{ik} + 1 = CAP - \sum_{j=1}^{k+1} p_j \quad \forall V_j \in (C'(v_i)) \quad \text{Where } p_{ij} \leq p_j \quad \forall i \text{ and } j$$

Hence, for every $fc(v_i)$, $fc_p(v_i) = \{p_{ij} \mid 1 \leq j \leq k+1, \text{ or } k\}$

Step 4: $cp_i = \sum_{V_j \in fc(v_i)} p_{ij}$ if is the total population covered by facility at v_i , and calculate for each village i ,

$$t_i = \sum_{V_j \in fc(v_i)} d_{ij} * p_{ij}$$

$$IDX(v_i) = (1 + |1 - cp_i/CAP|)$$

The village with minimum index IDX leads to the choice of location for the health care facility.

The Alternatives Scenarios:

- A) Minimize total cost: the village location where total cost of facilities in the block can be minimized. Cost per unit distance is multiplied to the distances to determine the cost as assigning a location to a facility. Cost scaled by demand is optional and on choosing this, cost formula also involves the demand of location as multiplier.
- B) Maximize the demand covered: Choosing the village with highest capacity utilization.

$$\text{Minimize } df_i = |\sum_{V_j \in fc(v_i)} p_{ij} - CAP|$$

- C) Minimize maximum service distance: Choosing the village location where total distance travelled by the population is minimized.

$$\text{Minimize } t_i = \sum_{v_j \in fc(v_i)} d_{ij} * p_{ij}$$

Step 5: Find the set of uncovered villages by eliminating the completely covered villages and start Step 3 of the process.

The solution parameter settings for all the alternate scenarios i.e. Minimize total cost, Maximize demand covered and minimize maximum service distance, are:

Cost per unit distance: The distances are multiplied by this amount (Rs 1) to determine the cost as assigning a location to a facility. This relationship is built into the Costs and Coverage worksheet as a formula.

Costs scaled by demand: The assignment cost of a location to a facility may depend on the demand of the location. If the option Yes is selected, the cost formula also involves the demand of the location as a multiplier. For solutions, with objective of minimize maximum service distance, the option 'Yes' is selected.

Service distance limit: Assigning a location to a facility at a distance more than the value of this parameter is prohibited, and a solution involving such an assignment is considered infeasible. The infeasibility is indicated in the solution through red coloured entries.

Coverage distance limit: Assigning a location to a facility at a distance more than the value of this parameter results in a coverage of 0.

This process can be stopped on finding location for all the villages in the block. The detailed solution obtained is available in the excel file, the information related to name and purpose of the file is depicted in Table 14.

In Tappal block, according to the census data 2011, 5 villages out of 92 has 0 population [695, 696, 701, 708, 784] = [Fazilpur Kachh, Shamaspur, Dorpuri, Bijaitha, Milak Jarana. The relative information of the medical facilities in block Tappal is presented in Table 3. There exist serious deficiencies in several of the selected villages in terms of water supply, all weather roads, travelling facilities, sanitization and other rural infrastructure.

According to the census 2011, the decennial growth rate of rural UP is 17.96%, the same rate is assumed to estimate the population of 2020 and is calculated to be 2.23 Lakhs (0.223 million). The distance from v_i to the health facility is calculated as $\min\{\text{CHC, PHC, SC, Mobile HC}\}$ and zero if the facility is available, around 14 villages data on distance to nearest health facility is not available in government data and is estimated using Google map. The government data contains information in distance range nominally presented as a, b and c where, a for < 5 Kms, b for 5-10 Kms and c for 10+ kms. The numerical value considered for this work is $a=5$, $b=7.5$, $c=10$. The villages where doctors are shown to be present but has number of CHC, PHC and SC as 0, are considered to have mobile health clinics. The map of block Tappal is given in Figure 2.

Locating CHC

There is a requirement of one more CHC at block Tappal. For identifying the candidate site for CHC the guidelines suggested in the model citizens charter for CHCs is followed, which states that: it should be near to all weather road, near the block head quarter, should have the facility for electricity, communication, adequate water supply, telephone and should not be situated at low lying areas. Giving the priority to all weather road, i.e. state highway the candidate sites were those having population more than 2400. The set of candidate sites were {729, 732, 767, 777} = **{Itwarpur, Kheriabuzurg, Jartauli, Takipur}**. The solution obtained with an objective of maximize demand covered is presented in Figure 3 and solution summary for all the three scenarios is presented in Table 4. The infeasibilities of the solution are reported in Table 5.

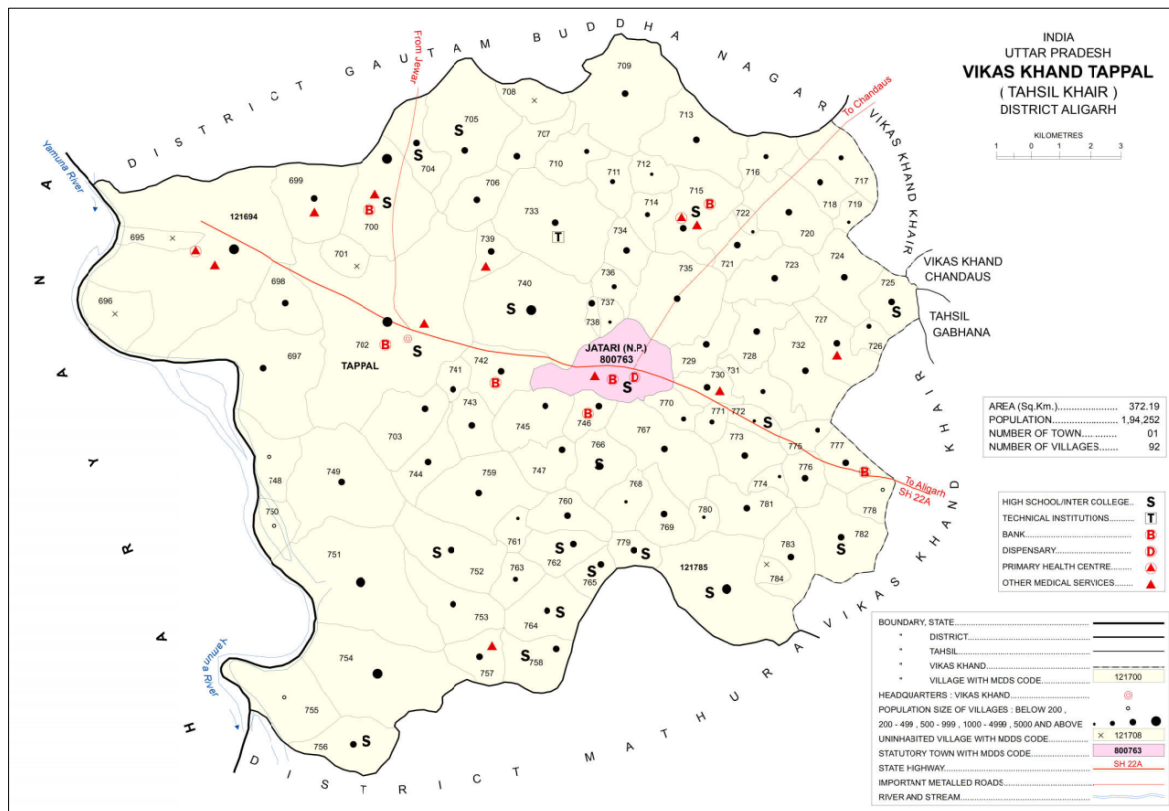


Figure 2: Map of block Tappal

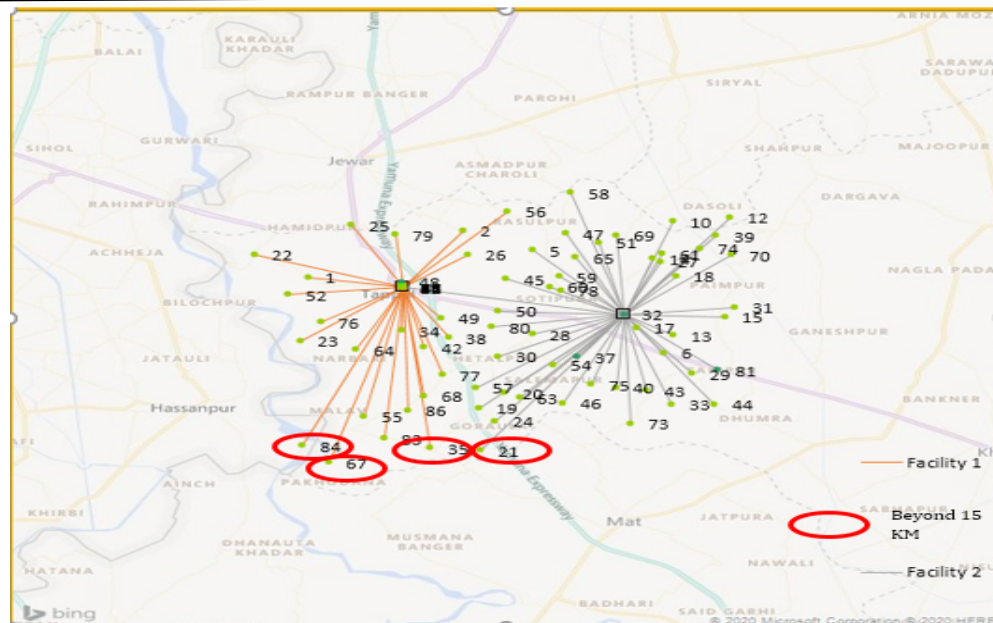


Figure 3: Solution sites for maximize demand covered at CHC for block Tappal

The locations which are unserved, are considered as 'Must have facility' for the next heuristic to find PHC and SC locations. If the population is more than 2000 then a PHC is suggested, whereas for population around 1000, a SC is suggested.

Locating PHC

There is a requirement of six more PHCs apart from available three (Gharvara (694), Tappal (702) and Palsera (715)) at block Tappal. For identifying the candidate sites for PHCs the guidelines suggested in the model citizens charter is followed with additional constraint of having population more than 2000 are candidates. The set of candidate sites contain 44 villages i.e. {Lalpur Raiyatpur (697), Hamidpur (699), Syaraul (700), Jahan Garh (703), Burhaka (704), Baina(705), Atari (706), Manpur (707), Maur (709), Vasera (713), Shadipur (720), Bijana Ki Nagaliya (721), Damuaka (723), Paimpur (724), Balampur (725), Bulakipur (727), Jalalpur (728), Itwarpur (729), Kheriabuzurg (732), Bajauta (733), Usarah Rasulpur (735), Harji Ki Garhi Urf Garhi Suraj(739), Khandeha(740), Kurana (742), Taharpur (745), Hetalpur (747), Narbari (749), Malav (751), Palar (752), Utwara (753), Untasani Bangar (754), Jaidpura*(757), Ghanghauri* (758), Simrauthi (759), Faizuaka (762), Goraula (764), Naglia Goraula (765), Madak(766), Jartauli (767), Takipur (777), Khediya Khurd (779), Karanpur (781), Keelpur (782), Salpur (785)} (*village with 'Must have' PHC restriction, as they were part of infeasibilities in CHC allocation with population around 3000). The solution obtained with an objective of maximize demand covered is presented in Figure 4 and solution summary for all the three scenarios is presented in Table 6 to Table 8. The infeasibilities are reported in Table 9.

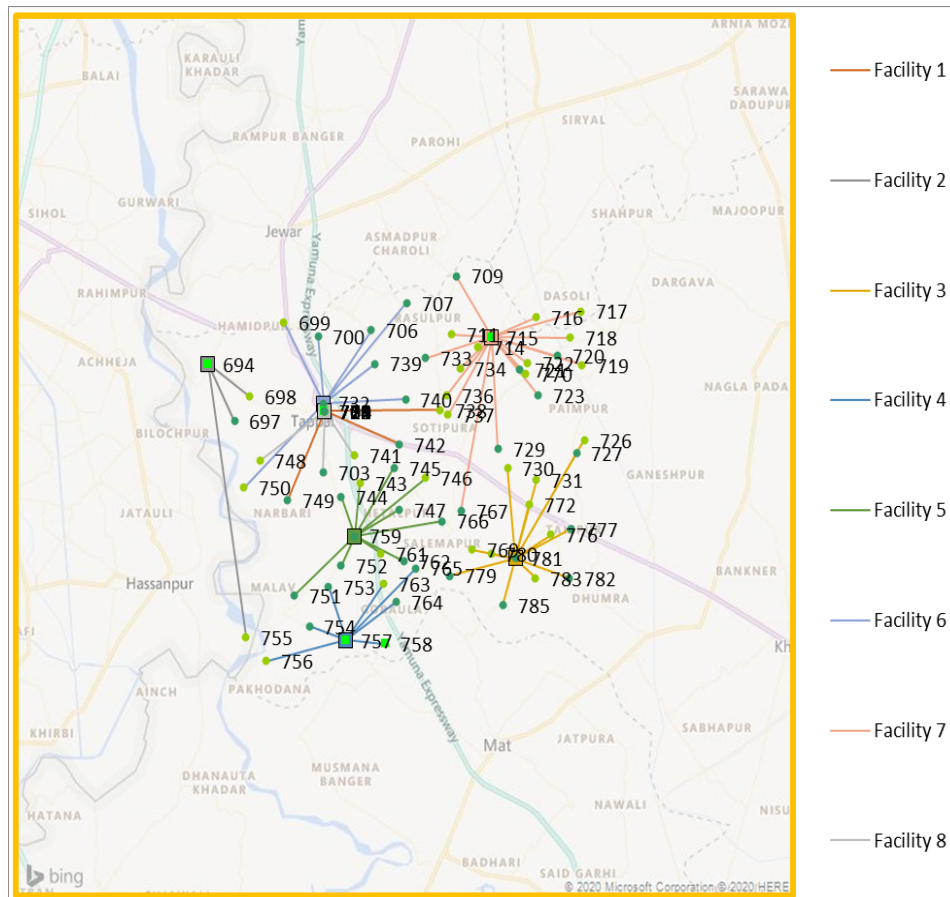


Figure 4:Solution sites for maximize demand covered at PHC for block Tappal

Locating SC

In Tappal block, there is one SC and nine mobile clinics, which are in total considered as ten SC available, there is deficit of 37 SCs. To choose the candidate sites the villages with higher population are preferred to get covered by PHC and villages with lesser population which are not been covered (primarily due to distance) by PHC should have a SC. The constraint of accessible all weather roads is relaxed in case of finding the candidate sites for SC. The candidate sites were all villages except Bajauta (733), Balampur (725), Ghanghauri (758), Gharvara (694), Itwarpur (729), Jaidpura (757), Karanpur (781), Kheriabuzurg (732), Kurana (742), Lal Garhi (714), Palsera (715), Shadipur (720), Simrauthi (759), Tappal (702) as they are either having/ proposed CHC or PHC. The solution obtained with an objective of maximize demand covered is presented in figure 5 and solution summary for all the three scenarios is presented in Table 10 to Table 12. The infeasibilities are reported in Table 13.

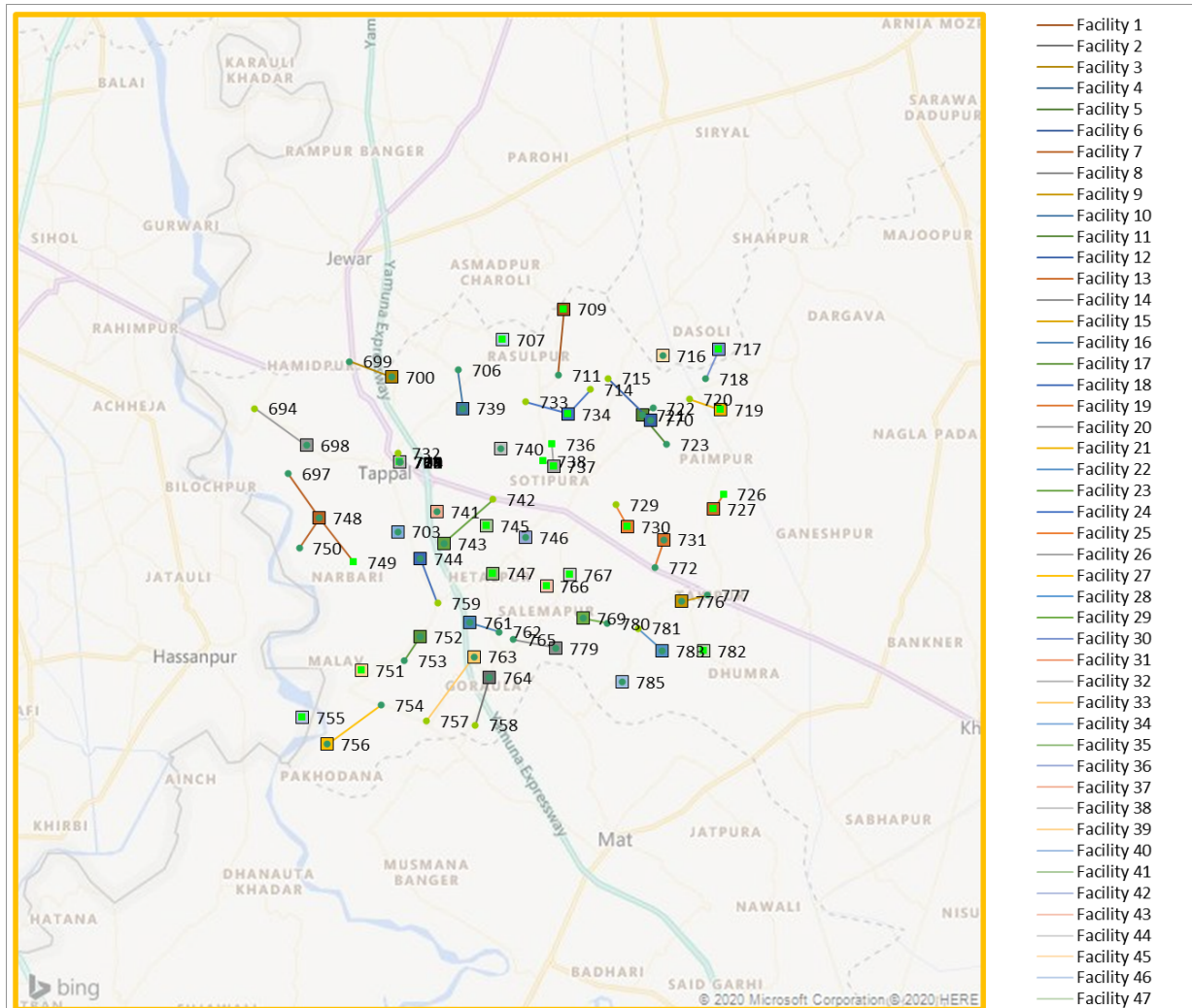


Figure 5:Solution sites for maximize demand covered at SC for block Tappal

For the objective of Maximize demand covered, the solution obtained had total estimated cost of 172 lakhs (17.2 Millions), Total demand covered was 1.72 lakh people, which met all the ideal constraints of distance and the maximum service distance (including the infeasibilities) is 4.3 kms.

For the objective of Minimize maximum service distance, the solution obtained had total cost incurred of 175 lakhs, total demand covered was 1.75 lakh people, which met all the ideal constraints of distance and the maximum service distance (including the infeasibilities) is 4.3 kms. For the objective of Minimize total cost, the solution obtained had total estimated cost of 173 lakhs, total demand covered was 1.70 lakhs people, which met all the ideal constraints of distance and the maximum service distance (including the infeasibilities) is 4.5 kms.

RESULTS AND DISCUSSION

The paper presents a methodology that can be implemented through the use of popular spreadsheets to generate solutions towards optimal location planning of CHC, PHC and SC for any block in India. The study area of the block Tappal is selected from Western Uttar Pradesh. The model allows handling of many alternative scenarios through various objective functions (such

as maximum demand covered, minimize max service distance and minimize total cost; handling the constraints on cost per unit distance, costs scaled by demand, service distance limit and coverage distance limit.) The distance calculations were obtained through the global map service "Bing". The driving distances (km) was used in the solution. The study used a heuristic model and considers some infeasibilities, which might be difficult to remove (for example a village in the block is separated by Yamuna river may not satisfy the distance-based constraints.)

Itwarpur is identified as the optimal location for second CHC in the Tappal apart from one existing at Tappal village. Itwarpur satisfies all the objective functions. The locations identified for PHCs apart from the current existing at Tappal, Gharvara and Palsera are; Karanpur, Jaidpura, Simrauthi, Kheriabuzurg, Balampur (for the objective function of Max demand covered); Karanpur, Itwarpur, Shadipur, Jaidpura, Ghanghauri, (for the objective function of Minimizing Maximum Service Distance) and Karanpur, Kurana, Shadipur, Jaidpura, Simrauthi, (for the objective function of Minimize total cost). If the PHCs are to be constructed in phased manner the locations Karanpur, Jaidpura, Simrauthi shall be preferred as they were present in solution set for all the scenarios.

For SC, 47 locations were identified for each of the objective function. For Minimize total cost the villages in the solution set were {Khandeha, Goraula, Untasani Khadar, Jahan Garh, Kripalpur, Keelpur, Hasanpur Jarailia, Hetalpur, Salpur, Jartauli, Malav, Bhojaka, Madak, Haziypur, Takipur, Maur, Taharpur, Bhadiyar, Bichpuri, Khera Kishan, Dewaka, Rasulpur, Baina, Shahnagar Soraula, Bharatpura, Untasani Bangar, Sotipura, Chhajjupur, Niguna Siguna, Jikarpur, Jadana, Pipli Nagala Kadirpur, Usarah Rasulpur, Kansera, Palar, Faizuaka, Lohlari, Harsukh Ki Nagaliya, Bulakipur, Nagala Kripa, Paimpur, Sherpur, Atari, Baluapur, Hamidpur, Nagla Danda, Adampur.} For the objective of Minimize maximum service distance the villages in the solution set were {Taharpur, Keelpur, Bhadiyar, Manpur, Jartauli, Untasani Khadar, Madak, Salpur, Malav, Khandeha, Narbari, Hasanpur Jarailia, Hetalpur, Khediya Khurd, Dewaka, Baluapur, Baina, Bhojaka, Shahnagar Soraula, Lohlari, Pakhodana, Nagala Khurd, Chhajjupur, Niguna Siguna, Jikarpur, Jadana, Pipli Nagala Kadirpur, Adampur, Bajhera, Kansera, Palar, Faizuaka, Jalalpur, Hirpura, Bijana Ki Nagaliya, Harsukh Ki Nagaliya, Harji Ki Garhi, Takipur, Jahan Garh, Bharatpura, Sherpur, Usarah Rasulpur, Nagla Danda, Rasulpur, Syaraul, Goraula, Maur.} And, for the objective of Maximize demand covered the villages in the solution set were {Keelpur, Manpur, Bhadiyar, Jartauli, Madak, Untasani Khadar, Taharpur, Salpur, Malav, Khandeha, Kripalpur, Hasanpur Jarailia, Hetalpur, Jahan Garh, Dewaka, Baluapur, Baina, Bhojaka, Shahnagar Soraula, Lohlari, Pakhodana, Sotipura, Chhajjupur, Niguna Siguna, Jikarpur, Jadana, Pipli Nagala Kadirpur, Adampur, Bichpuri, Kansera, Palar, Marorgarhi, Jalalpur, Khediya Khurd, Bulakipur, Harsukh Ki Nagaliya, Bijana Ki Nagaliya, Harji Ki Garhi, Haziypur, Bharatpura, Sherpur, Usarah Rasulpur, Rasulpur, Salemapur, Syaraul, Goraula, Maur.}

MANAGERIAL IMPLICATIONS OF THE STUDY

The solution obtained for the optimization problem for the selected Tappal Block of western Uttar Pradesh. The potential for applying the methodology is illustrated through the location visualized on geographical map along with covered villages. The paper successfully demonstrates that the use of advancement of computers along with judicious O.R. methodology can help in improving the quality of location decisions of the block level decision makers involved in achieving the national level health care goals. The success, in terms of adoption of this

methodology depends on the utility perceived by the user departments at the local levels. The programs although satisfies the planning issues for a specific block but can be suitably modified for use in any other block/district in India. If utilized in planning, it will help improve the gains from health care services in achieving the goals set under National Health Policy thereby achieving Millennium Development Goals and the goal of Health for All in India.

References

- [1] MOHFW, Govt. of India. (2017). Reports | Ministry of Health and Family Welfare| GOI. Retrieved October 11, 2018, from National Health Portal: https://www.nhp.gov.in//NHPfiles/national_health_policy_2017.pdf
- [2] GOI. (2018). Health management information system. Retrieved from <https://nrhm-mis.nic.in>
- [3] Daskin, M. S., & Dean, L. K. (2004). Location of health care facilities. In *Operations Research & Health Care: A Handbook of Methods & Applications* (pp. 43-76).
- [4] Owen, S. H., & Daskin, M. S. (1998). Strategic facility location: A review. *European Journal of Operational Research*, 111, 423-447. doi:10.1016/S0377-2217(98)00186-6
- [5] Gu, W. W. (2010). Optimization of preventive health care facility locations. *International Journal of Health Geographics*, 9. doi:<https://doi.org/10.1186/1476-072X-9-17>
- [6] Sinuany-Stern, Z., Mehrez, A., Tal, A. G., & Shemuel, B. (1995). The location of a hospital in a rural region: the case of the Negev. *Location Science*, 3, 255-266.
- [7] Jacobs, D. A., Silan, M. N., & Clemson, B. A. (1996). An analysis of alternative locations and service areas of American Red Cross blood facilities. *Interface*, 26(3), 40-50.
- [8] Church, R. L., & ReVelle, C. S. (1974). The maximal covering location problem. *Papers of the Regional Science Association*, 32, 101-118.
- [9] Morrill, R. L., & Earickson, R. (1968). Hospital Variation and Patient Travel Distances. *Inquiry*, 5, 26-34.
- [10] Morrill, R., & Earickson, R. (1968). Variation in the Character and Use of Chicago Area Hospitals. *Health Services Research*, 3, 224-238
- [11] Morrill, R., & Earickson, R. (1969). Location Efficiency of Chicago Hospitals: An Experimental Model. *Health Services Research*, 4, 128-141.
- [12] Meade, J. (1974). A Mathematical Model for Deriving Hospital Service Areas. *International Journal of Health Services*, 4, 353-864.
- [13] McLafferty, S. (1988). Predicting the effect of hospital closure on hospital utilization patterns. *Social Science and Medicine*, 27, 255-262.
- [14] McGuirk, M., & Porell, F. (1984). Spatial Patterns of Hospital Utilization: The Impact of Time and Distance. *Inquiry*, 21, 84-95.
- [15] Price, W., & Turcotte, M. (1986). Locating blood bank. *Interfaces*, 16, 17-26.
- [16] Morrill, R. L., & Kelley, P. (1969). Optimum allocation of services: An hospital example. *The Annals of Regional Science*, 3(1), 55-66.
- [17] Vitaliano, D. F. (1988). Assessing the locational efficiency of a system of hospitals. *Applied Economics*, 20(8), 1087-1098.
- [18] McAleer, W., & Naqvi, I. (1994). The relocation of ambulance stations: A successful case study. *European Journal of Operations Research*, 75, 582-588.
- [19] Yeh, A. G. O., & Chow, M. H. (1996). An integrated GIS and location-allocation approach to public facilities planning—an example of open space planning. *Computers, Environment and Urban Systems*, 20(4-5), 339-350.
- [20] Chu, S. C., & Chu, L. (2000). A modeling framework for hospital location and service allocation. *International transactions in operational research*, 7(6), 539-568.

- [21] Griffin, P. M., Scherrer, C. R., & Swann, J. L. (2008). Optimization of community health center locations and service offerings with statistical need estimation. *IIE transactions*, 40(9), 880-892.
- [22] Mestre, A. M., Oliveira, M. D., & Barbosa-Póvoa, A. (2012). Organizing hospitals into networks: a hierarchical and multiservice model to define location, supply and referrals in planned hospital systems. *OR spectrum*, 34(2), 319-348.
- [23] Zhang, Y., Berman, O., & Verter, V. (2012). The impact of client choice on preventive healthcare facility network design. *OR spectrum*, 34(2), 349-370.
- [24] Chaturvedi, S. (2015, May). Comparing Western UP and Bundelkhand Human Development, Gender and Deprivation. *Economic & Political Weekly*, 50(20). Retrieved from <https://www.epw.in/journal/2015/20/reports-states-web-exclusives/comparing-western-and-bundelkhand.html>
- [25] Datta, S., & Bandyopadhyay, R. (1993). An application of O.R. in micro level planning in India. *Computers and Operations Research*, 20(2), 121-132.
- [26] Prinja S, G. A. (2016). Cost of Delivering Health Care Services in Public Sector Primary and Community Health Centres in North India. *PLoS One*, 11(8). doi:10.1371/journal.pone.0160986
- [27] Chapagain, M. (2017, 2 20). Mukesh Chapagain Blog. Retrieved from <http://blog.chapagain.com.np/google-appscript-get-latitude-longitude-distance-between-places-city/>

TABLES**Table 2: Uttar Pradesh shortfall of health care infrastructure in 2018**

	Total functioning	Govt. Building	Rented Building	Required	Shortfall	Shortfall %
Sub Centres	20521	18166	2355	31200	10679	34
PHCs	3621	3516	105	5194	1573	30
CHCs	822	822	0	1298	476	37

Table 3: Relative information of the medical facility in Tappal

Type of facility	No. of facilities in the block	% of doctors available	% of paramedic available	Additional Information	Deficit based on prescribed coverage.
CHC	1	3/6 = 50%	5/9=55.6%	at ('village number) 702 (village) Tappal	1
PHC	2	3/3 =100%	6/8 = 75%	At 715Palsera 694 Gharvara	6
SC	10	8/11	7/13	'702 Tappal, operating in building. (8 Mobile Health Clinic)	37
Non Gov Facilities (NGF)	38-22 =16	11-1=10	13-3 =10	22 of 38 are in Tappal	

* estimated population in year 2020 = 2,32,530

Table 4: Solution summary for CHC at block Tappal

Candidate Set (ID-Name- Population)	Solution				
	729-Itwarpur-2630, 767-Jartauli-3250, 732-Kheriabuzurg-4460, 777-Takipur-2440	Total Cost incurred	Total Demand Covered	Max service distance	Facility location
Objective					
Maximize demand covered	1619015.13	151590	38.00*		Tappal [Exists]
		86580	214.312		Itwarpur [Proposed]
Remarks (What if: other candidate site used)					
					1. Tappal 7 3 0 Itwarpur 17 1 0 2. Jartauli 19 3 18.87 3. Kheriabuzurg 39 21 233.56 4. Takipur 32 12 117.42
Minimize Total Cost	1619026.55	150630	38.00*		Tappal [Exists]
		85620	200.01		Itwarpur [Proposed]
Remarks (What if: other candidate site used)					1. Tappal 8 3 0 Itwarpur 19 1 0 2. Jartauli 21 3 16.75 3. Kheriabuzurg 38 21 222.14 4. Takipur 34 14 126.21
Minimize Max Service Distance [cost scaled by demand]	1619034.71	143550	38.00*		Tappal [Exists]
		88810	593493* Scaled by demand		Itwarpur [Proposed]
Remarks (What if: other candidate site used)					1. Tappal 7 3 0 Itwarpur 19 1 0 2. Jartauli 20 3 - 3. Kheriabuzurg 39 21 - 4. Takipur 34 12 - [since cost is scaled by demand the values are not interpretable as normal cost]

*Max service distance is due to a village 755 Untasani Khadar, separated by river Yamuna

Table 5: Infeasibilities in solution for CHC for block Tappal

Solution Objective	Infeasible Location	Distance from facility	Population affected	Forward feed for facility consideration
Minimize total cost	Jaidpura	16.5 KM from Tappal	2930	PHC
	Pakhodana	17.13 KM from Tappal	1520	SC
	Untasani Khadar	38.01 KM from Tappal	170	SC
	Ghanghauri	15.14 KM from Tappal	3840	PHC
Minimize	Pakhodana	17.13 KM from Tappal	1520	SC
Max service distance**	Untasani Khadar	38.01 KM from Tappal	170	SC
	Jaidpura	16.5 KM from Tappal	2930	PHC
	Ghanghauri	15.14 KM from Tappal	3840	PHC
Maximum demand covered	Pakhodana	17.13 KM from Tappal	1520	SC
	Untasani Khadar	38.01 KM from Tappal	170	SC
	Jaidpura	16.5 KM from Tappal	2930	PHC
	Ghanghauri	15.14 KM from Tappal	3840	PHC

* separated by river Yamuna **cost scaled by demand

Table 6: Summary for max demand covered -solution for PHC at block Tappal

Objective	Total Cost incurred	Total Demand Covered	Max service dist.	Facility location	Demand allocated	Demand covered	Cost incurred	Remarks Total Villages allocated PHC at Villages beyond 5 km villages beyond 7.5 km
Maximize demand covered	3059886.44	146310	31.67	Tappal [Exists]	34190	29740	18.51	6 Tappal 1 2 3.1 4 Gharvara 1 1 9.9 19 Palsera 5 10 5.2 14 Karanpur 4 6 5.2 8 Jaidpura 0 3 4.3 11 Simrauthi 1 5 4 12 Kheriabuzurg 0 7 3.8 13 Balampur 0 1 1
				Gharvara [Exists]	17960	17790	39.668	
				Palsera [Exists]	35840	14530	99.329	
				Karanpur [Proposed]	29410	18820	611976.43	
				Jaidpura *[Proposed]	25670	17990	611938.10	
				Simrauthi [Proposed]	29560	11490	611948.03	
				Kheriabuzurg [Proposed]	29900	6060	611949.87	
				Balampur [Proposed]	30000	29890	611916.50	

Table 7: Summary for minimize max service distance -solution for PHC at block Tappal

Objective	Total Cost incurred	Total Demand Covered	Max service distance	Facility location	Demand allocated	Demand covered	Cost incurred	Remarks
Minimize Max Service Distance [cost scaled by demand] 7				Tappal	89410	57320	225943.7	Total Villages allocated PHC at Villages beyond 5 km villages beyond 7.5 km 31 Tappal 0 11 2.6 5 Gharvara 2 2 9.5 8 Palsera 1 3 3.7 8 Karanpur 1 1 3.3 11 Itwarpur 0 8 5.2 10 Shadipur 0 3 3.3 5 Jaidpura 0 2 3.7 9 Ghanghauri 1 6 5.1
				Gharvara [Exists]	23730	17790	81018.29	
				Palsera [Exists]	21470	10160	85394.77	
				Karanpur [Proposed]	21210	18430	681146.45	
			31.67	Itwarpur [Proposed]	20910	4600	724062.67	
		139140		Shadipur [Proposed]	13010	8940	653527.26	
				Jaidpura [Proposed]	22280	13230	690738.2	
				Ghanghauri [Proposed]	20510	8670	704916.03	

Table 8: Summary for Minimize total cost -solution for PHC at block Tappal

Objective	Total Cost incurred	Total Demand Covered	Max service distance	Facility location	Demand allocated	Demand covered	Cost incurred	Remarks
Minimize Total Cost	3671785.91	153200	31.673	Tappal [Exists]	51980	34850	46.674	Total Villages allocated PHC at Villages beyond 5 km villages beyond 7.5 km Average distance 16 Tappal 0 7 2.9 4 Gharvara 1 1 9.9 10 Bajauta 0 1 3.2 11 Karanpur 1 3 4.1 12 Kurana 0 4 4.5 13 Shadipur 0 5 3.7 7 Jaidpura 0 4 4.3 14 Simrauthi 1 7 4.7 *Palsera has existing facility but not found to increase the cost than proposed solution
				Gharvara [Exists]	17960	17790	39.668	
				Bajauta [Proposed]	25990	21960	611936.49	
				Karanpur [Proposed]	24950	18820	611949.19	
				Kurana [Proposed]	29940	20090	611957.90	
				Shadipur [Proposed]	21970	11220	611951.80	
				Jaidpura [Proposed]	29750	14540	611934.19	
				Simrauthi [Proposed]	29990	13930	611970.01	

Table 9: Infeasibilities in solution for PHC for block Tappal

Solution Objective	Infeasible Location*	Distance from facility	Population affected
Maximum demand covered	Nagala Khurd	8.76	1570
	Untasani Khadar	31.67	170
	Chhajjupur	8.28	1580
	Hirpura	10.32	610
	Keelpur	7.52	2780
	Bulakipur	8.64	2270
	Madak	7.51	2960
	Nagal Kala	8.97	820
	Sotipura	8.1	560
	Pipli Nagala Kadirpur	7.7	470
	Bhojaka	8.97	1190
	Jartauli	10.88	3250
Minimize Max service distance	Untasani Khadar	31.673	170
	Baina	7.743	5770
	Manpur	8.37	3020
	Keelpur	7.524	2780
	Hetalpur	8.523	2540
Minimize total cost	Untasani Khadar	31.673	170
	Keelpur	7.524	2780
	Madak	7.513	2960

* Forward feed for facility in infeasible solution considered for location of SC

Table 10: Locations identified for SC with objective of Maximize demand covered for Tappal block

#	Facility location	Demand allocated	Demand covered	Cost incurred	Total Villages allocated SC at Villages beyond 3 km villages beyond 2 km Average distance
1	Maur	4950	4030	367145.41	2 Maur 1 1 1.7
2	Goraula	7750	3910	367144.61	2 Goraula 0 1 1.3
3	Syraul	10200	6580	367144.41	2 Syraul 0 1 1.2
4	Salemapur	4900	4900	367142.00	3 Salemapur 0 0 0
5	Rasulpur	4590	4590	367142.00	2 Rasulpur 0 0 0
6	Usarah Rasulpur	4990	4990	367142.00	2 Usarah Rasulpur 0 0 0
7	Sherpur	8180	110	367152.08	4 Sherpur 2 3 2.5
8	Bharatpura	4680	4680	367142.00	3 Bharatpura 0 0 0
9	Haziya	4410	4410	367143.56	2 Haziya 0 0 0.8
10	Harji Ki Garhi	4450	4450	367143.49	2 Harji Ki Garhi 0 0 0.7
11	Bijana Ki Nagaliya	4980	2700	367145.05	3 Bijana Ki Nagaliya 0 1 1
12	Harsukh Ki Nagaliya	4660	610	367145.02	2 Harsukh Ki Nagaliya 1 1 1.5
13	Bulakipur	2880	2880	367143.20	2 Bulakipur 0 0 0.6
14	Khediya Khurd	4750	2500	367144.40	2 Khediya Khurd 0 1 1.2
15	Jalalpur	4900	4900	367142.00	2 Jalalpur 0 0 0
16	Marorgarhi	2540	2540	367143.94	2 Marorgarhi 0 0 1
17	Palar	4540	4540	367143.69	2 Palar 0 0 0.8
18	Kansera	4640	2000	367144.33	2 Kansera 0 1 1.2
19	Bichpuri	1240	1240	367143.67	2 Bichpuri 0 0 0.8
20	Adampur	12620	1830	367145.11	2 Adampur 1 1 1.6
21	Pipli Nagala Kadirpur	2740	470	367144.75	2 Pipli Nagala Kadirpur 0 1 1.4
22	Jadana	4280	4280	367143.70	2 Jadana 0 0 0.9
23	Jikarpur	6380	1780	367145.17	2 Jikarpur 1 1 1.6
24	Niguna Siguna	7170	2910	367146.73	3 Niguna Siguna 0 1 1.6
25	Chhajjupur	4210	4210	367143.40	2 Chhajjupur 0 0 0.7
26	Sotipura	2950	2950	367144.36	3 Sotipura 0 0 0.8
27	Pakhodana	9290	1520	367146.27	2 Pakhodana 1 1 2.1
28	Lohlari	20890	20890	367142.00	2 Lohlari 0 0 0
29	Shahnagar Soraula	1810	1300	367144.11	2 Shahnagar Soraula 0 0 1.1
30	Bhojaka	3020	3020	367143.57	2 Bhojaka 0 0 0.8

31	Baina	6770	6770	367142.00	2 Baina 0 0 0
32	Baluapur	4940	4940	367142.51	2 Baluapur 0 0 0.3
33	Dewaka	3850	920	367146.29	2 Dewaka 1 1 2.1
34	Jahan Garh	2770	2770	367142.00	1 Jahan Garh 0 0 0
35	Hetalpur	2540	2540	367142.00	1 Hetalpur 0 0 0
36	Hasanpur Jarailia	1700	1700	367142.00	1 Hasanpur Jarailia 0 0 0
37	Kripalpur	1660	1660	367142.00	1 Kripalpur 0 0 0
38	Khandeha	6150	6150	367142.00	1 Khandeha 0 0 0
39	Malav	7530	7530	367142.00	1 Malav 0 0 0
40	Salpur	7930	7930	367142.00	1 Salpur 0 0 0
41	Taharpur	3860	3860	367142.00	1 Taharpur 0 0 0
42	Untasani Khadar	170	170	367142.00	1 Untasani Khadar 0 0 0
43	Madak	2960	2960	367142.00	1 Madak 0 0 0
44	Jartauli	3250	3250	367142.00	1 Jartauli 0 0 0
45	Bhadiyar	1060	1060	367142.00	1 Bhadiyar 0 0 0
46	Manpur	3020	3020	367142.00	1 Manpur 0 0 0
47	Keelpur	2780	2780	367142.00	1 Keelpur 0 0 0

Table 11:Locations identified for SC with objective of Minimize maximum service distance for Tappal block.

#	Facility location	Demand allocated	Demand covered	Cost incurred	Total Villages allocated SC at Villages beyond 3 km villages beyond 2 km Average distance
1	Maur	4950	4030	370275.52	2 Maur 1 1 1.7
2	Goraula	7750	3910	377168.24	2 Goraula 0 1 1.3
3	Syaraul	10200	6580	375880.68	2 Syaraul 0 1 1.2
4	Rasulpur	4660	4660	367142.00	2 Rasulpur 0 0 0
5	Nagla Danda	4880	4880	367142.00	3 Nagla Danda 0 0 0
6	Usarah Rasulpur	4990	4990	367142.00	2 Usarah Rasulpur 0 0 0
7	Sherpur	5300	110	387821.68	3 Sherpur 1 2 2
8	Bharatpura	4790	4790	367142.00	3 Bharatpura 0 0 0
9	Jahan Garh	4430	2770	371305.28	2 Jahan Garh 0 1 1.3
10	Takipur	4410	4410	370207.32	2 Takipur 0 0 0.8
11	Harji Ki Garhi	4450	4450	370319.90	2 Harji Ki Garhi 0 0 0.7
12	Harsukh Ki Nagaliya	4660	610	379368.95	2 Harsukh Ki Nagaliya 1 1 1.5
13	Bijana Ki Nagaliya	4980	2700	372220.52	3 Bijana Ki Nagaliya 0 1 1
14	Hirpura	2880	2880	369859.19	2 Hirpura 0 0 0.6
15	Jalalpur	4900	4900	367142.00	2 Jalalpur 0 0 0
16	Faizuaka	4790	4790	369900.20	3 Faizuaka 0 0 0.9
17	Palar	4540	4540	371427.82	2 Palar 0 0 0.8
18	Kansera	4640	2000	373290.56	2 Kansera 0 1 1.2
19	Bajhera	1240	1240	368562.35	2 Bajhera 0 0 0.8
20	Adampur	12620	1830	400666.53	2 Adampur 1 1 1.6
21	Pipli Nagala Kadirpur	2740	470	373389.04	2 Pipli Nagala Kadirpur 0 1 1.4
22	Jadana	4280	4280	371362.96	2 Jadana 0 0 0.9
23	Jikarpur	6380	1780	381737.80	2 Jikarpur 1 1 1.6
24	Niguna Siguna	7170	2910	381218.90	3 Niguna Siguna 0 1 1.6
25	Chhajjupur	4210	4210	370818.74	2 Chhajjupur 0 0 0.7
26	Nagala Khurd	2950	2950	369057.38	3 Nagala Khurd 0 0 0.9
27	Pakhodana	9290	1520	400281.05	2 Pakhodana 1 1 2.1
28	Lohlari	20890	20890	367142.00	2 Lohlari 0 0 0
29	Shahnagar Soraula	1810	1300	368219.12	2 Shahnagar Soraula 0 1 1.1
30	Bhojaka	3020	3020	370009.61	2 Bhojaka 0 0 0.8
31	Baina	6610	6610	367142.00	2 Baina 0 0 0

32	Baluapur	4940	4940	369403.22	2 Baluapur 0 0 0.3
33	Dewaka	3850	920	379708.77	2 Dewaka 1 1 2.1
34	Khediya Khurd	2500	2500	367142.00	1 Khediya Khurd 0 0 0
35	Hetalpur	2540	2540	367142.00	1 Hetalpur 0 0 0
36	Hasanpur Jarailia	1700	1700	367142.00	1 Hasanpur Jarailia 0 0 0
37	Narbari	2880	2880	367142.00	1 Narbari 0 0 0
38	Khandeha	6150	6150	367142.00	1 Khandeha 0 0 0
39	Malav	7530	7530	367142.00	1 Malav 0 0 0
40	Salpur	7930	7930	367142.00	1 Salpur 0 0 0
41	Madak Untasani	2960	2960	367142.00	1 Madak 0 0 0
42	Khadar	170	170	367142.00	1 Untasani Khadar 0 0 0
43	Jartauli	3250	3250	367142.00	1 Jartauli 0 0 0
44	Manpur	3020	3020	367142.00	1 Manpur 0 0 0
45	Bhadiyar	1060	1060	367142.00	1 Bhadiyar 0 0 0
46	Keelpur	2780	2780	367142.00	1 Keelpur 0 0 0
47	Taharpur	3860	3860	367142.00	1 Taharpur 0 0 0

Table 12: Locations identified for SC with objective of Minimize total cost for Tappal block

Facility #	location	Demand allocated	Demand covered	Cost incurred	Total Villages allocated SC at Villages beyond 3 km villages beyond 2 km Average distance
1	Adampur	12620	1830	367145.11	2 Adampur 1 1 1.6
2	Nagla Danda	4780	4780	367142	4 Nagla Danda 0 0 0
3	Hamidpur	10200	3620	367144.41	2 Hamidpur 0 1 1.2
4	Baluapur	4940	4940	367142.51	2 Baluapur 0 0 0.3
5	Atari	7470	4450	367146.82	3 Atari 1 1 1.6
6	Sherpur	8180	110	367152.08	4 Sherpur 2 3 2.5
7	Paimpur	4960	4960	367142	2 Paimpur 0 0 0
8	Nagala Kripa	4980	2700	367145.24	3 Nagala Kripa 0 1 1.1
9	Bulakipur	2880	2880	367143.2	2 Bulakipur 0 0 0.6
10	Harsukh Ki Nagaliya	4660	610	367145.02	2 Harsukh Ki Nagaliya 1 1 1.5
11	Lohlari	20890	20890	367142	2 Lohlari 0 0 0
12	Faizuaka	4790	4790	367144.66	3 Faizuaka 0 0 0.9
13	Palar	4540	4540	367143.69	2 Palar 0 0 0.8
14	Kansera	4640	2000	367144.33	2 Kansera 0 1 1.2
15	Usarah Rasulpur	4990	4990	367142	2 Usarah Rasulpur 0 0 0
16	Pipli Nagala Kadirpur	4570	470	367146.83	3 Pipli Nagala Kadirpur 0 2 1.6
17	Jadana	4280	4280	367143.7	2 Jadana 0 0 0.9
18	Jikarpur	6380	1780	367145.17	2 Jikarpur 1 1 1.6
19	Niguna	3730	3730	367145.93	3 Niguna Siguna 0 0 1.3
20	Chhajjupur	4210	4210	367143.4	2 Chhajjupur 0 0 0.7
21	Sotipura	2130	2130	367143.08	2 Sotipura 0 0 0.5
22	Untasani Bangar	12220	7770	367148.84	3 Untasani Bangar 1 2 2.3
23	Bharatpura Shahnagar	4830	4830	367142	2 Bharatpura 0 0 0
24	Soraula	4310	1300	367146.77	3 Shahnagar Soraula 0 2 1.6
25	Baina	6610	6610	367142	2 Baina 0 0 0
26	Rasulpur	4660	4660	367142	2 Rasulpur 0 0 0
27	Dewaka	4760	920	367146.23	2 Dewaka 1 1 2.1
28	Khera Kishan	5180	920	367144.32	2 Khera Kishan 0 1 1.2
29	Bichpuri	1240	1240	367143.67	2 Bichpuri 0 0 0.8
30	Bhadiyar	1060	1060	367142	1 Bhadiyar 0 0 0

31	Taharpur	3860	3860	367142	1 Taharpur 0 0 0
32	Maur	4030	4030	367142	1 Maur 0 0 0
33	Takipur	2440	2440	367142	1 Takipur 0 0 0
34	Haziypur	1970	1970	367142	1 Haziypur 0 0 0
35	Madak	2960	2960	367142	1 Madak 0 0 0
36	Bhojaka	1190	1190	367142	1 Bhojaka 0 0 0
37	Malav	7530	7530	367142	1 Malav 0 0 0
38	Jartauli	3250	3250	367142	1 Jartauli 0 0 0
39	Salpur	7930	7930	367142	1 Salpur 0 0 0
40	Hetalpur	2540	2540	367142	1 Hetalpur 0 0 0
41	Hasanpur Jarailia	1700	1700	367142	1 Hasanpur Jarailia 0 0 0
42	Keelpur	2780	2780	367142	1 Keelpur 0 0 0
43	Kripalpur	1660	1660	367142	1 Kripalpur 0 0 0
44	Jahan Garh Untasani	2770	2770	367142	1 Jahan Garh 0 0 0
45	Khadar	170	170	367142	1 Untasani Khadar 0 0 0
46	Goraula	3910	3910	367142	1 Goraula 0 0 0
47	Khandeha	6150	6150	367142	1 Khandeha 0 0 0

Table 13: Infeasibilities in solution for SC in Tappal Block

Solution Objective	Infeasible Location*	Distance from facility	Population affected
Maximum demand covered	Khera Kishan	3.41	920.00
	Narbari	4.04	2880.00
	Lalpur Raiyatpur	3.99	5170.00
	Palsera	3.02	4050.00
	Gharvara	3.11	10790.00
	Kurana	3.17	4600.00
	Untasani Bangar	4.27	7770.00
	Jaidpura	4.29	2930.00
Minimize Max service distance	Khera Kishan	3.41	920.00
	Lalpur Raiyatpur	3.99	5170.00
	Palsera	3.02	4050.00
	Gharvara	3.11	10790.00
	Kurana	3.17	4600.00
	Untasani Bangar	4.27	7770.00
	Jaidpura	4.29	2930.00
Minimize total cost	Gharvara	3.11	10790.00
	Manpur	3.34	3020.00
	Narbari	4.04	2880.00
	Lalpur Raiyatpur	3.99	5170.00
	Palsera	3.02	4050.00
	Kurana	3.17	4600.00
	Pakhodana	4.51	1520.00
	Ghanghauri	4.23	3840.00

Table 14: Information on Excel files containing detailed solution obtained after heuristic

Block	Solution for health facility	Objective	File name
Tappal	CHC	Maximize demand covered	Tappal CHC-Max demand coverage.xlsm
Tappal	CHC	Minimize Total Cost	Tappal CHC-Min Max service distance .xlsm
Tappal	CHC	Minimize Max Service Distance	Tappal CHC-Min Total Cost .xlsm