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Analysis and planning of infrastructural facilities in rural areas using facility index methods

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Abstract: Facility index calculation is a method of determining the availability of infrastructure and access to the infrastructure. It helps in ranking areas based on the availability and access to infrastructure. To rank group of areas based on infrastructure availability, a number of parameters have to be taken into consideration. In the present paper, weights for the available infrastructure for one Rural Administrative Unit (RAU) have been calculated using Weighted Index Method (WIM) and entropy method. WIM and Grey Relation Analysis (GRA) have been used to determine the overall facility index. The study has been carried out on Geesugondamandal, Warangal district, Telangana, India. Geographical Information System (GIS) is used to prepare spatial database of the available facilities. Thirteen parameters, which include the number of schools, hospitals, communication centres, market places, etc., have been considered and were assigned weights based on their relative importance. Based on the ranks obtained, spatial variation of ranks is studied and a group of three to four villages are combined to form a cluster based on Providing Urban amenities in Rural Areas (PURA) concept. Three clusters have been proposed and the infrastructure which is necessary for each cluster has also been identified. This will help government officials, planners and NGOs to take necessary action in planning of infrastructure and in decision making for development of rural areas.

Keywords: Entropy, Grey Relation Analysis (GRA), Infrastructure planning, Rural areas, Weighted Index Method (WIM)

1. Introduction

Infrastructure is the basic social and economic need which is essential for the development of any society. Infrastructure can be broadly classified in terms of social and economic categories. Sectors like health, education, housing etc. come under social infrastructure whereas economic infrastructure includes transportation, communication, irrigation, banking, market centres etc. Improvement in infrastructural services is essential for enhancing efficacy of the productive process and for raising productivity of any economic entity (Patra and Acharya, 2011).

Rural infrastructure plays a major role in increasing literacy, economic growth and empowerment of rural poor. Access to education, health, telecommunication, roads, etc. is important in reducing the vulnerability and increases prosperity. Infrastructure Facility Index (IFI) is a measure of infrastructure availability and is calculated by considering various indicators. It helps planners and government officials to know the status of development in rural areas and for preparation of developmental action plans.

Rives and Heaney (1995) analyzed various parameters which affect the community economic development. They studied the relationship between infrastructure availability and economic development using regression analysis and concluded that the level of economic development is positively affected by the physical infrastructure and location advantages. Ting and Hsin (1997) proposed a staged heuristic approach for solving infrastructure investment problem using grey relation approach and suggested that the approach can be implemented by public agencies which are responsible for routine infrastructure investment decisions. Fakayode et al. (2008) explained the effect of rural infrastructure in agricultural productivity. They have taken the farm level data from Ekiti state, Nigeria and analysed using ordinary least squares regression analysis. Fernando et al. (2012) introduced a modified factor analysis to construct the composite index by considering various infrastructural and demographical indicators. The weights for these indicators have been calculated using modified factor analysis which takes into account the principal components of the variables. Facility Index (FI) will help in preparation of development plans of village clusters using the concept of Providing Urban amenities in Rural Areas (PURA) (Kalam and Singh, 2011). PURA scheme aims to improve the quality of life in rural places which should lead to decongesting urban areas. "Instead of village population coming to urban areas, the reverse phenomenon has to take place" as said by Dr. A.P.J. Abdul Kalam, former president of India (www.pura.org.in) is the driving force for the PURAscheme. Geographical Information Systems (GIS) plays a major role in acquiring spatial data of infrastructure, storing the data, query with the data and analyse the data. It acts as a decision support system for planners making the work easier and effective.

Srivastava et al. (2004) studied the relation between poverty incidence and natural resources degradation in different states of India. They carried out waste land mapping using remote sensing and GIS techniques and studied the effect of macro-economic variables in determining the relation between poverty and natural resources degradation in rural India. Gupta (2007) proposed a geo-statistical model for assessing development at micro level. He developed a computer program in Arc Macro Language (AML) to find out the median population threshold, facility composite index and correlation matrix and village development index by calculating weights for various facilities using weighted index method. Ines et al. (2008) developed a system called RULES (Rural Land-use Exploration System) which is used as a planning system for rural land use allocation developed using hierarchical optimization, ideal point analysis and simulated annealing. Fu et al. (2008) have developed a spatial analyses system for urban land use management based on GIS and multi assessment model. They have used Grey Relation Analysis (GRA) combined with Analytic Hierarchy Process (AHP) to overcome the uncertainties in the evaluation of urban land management.

Garg (2008) explained the importance of GIS in infrastructure planning for Roorkee city. The rural areas have been prioritized using weighted index method and spatial analysis was carried out to understand the concentration of overall development. Umoren et al. (2009) employed the correlation analysis to determine the relationship between road infrastructure and socio-economic activity variables. They found out that there exists a positive correlation between the road infrastructure and socio-economic activity. Patra and Acharya (2011) studied the spatial disparities in infrastructural facilities for 16 states of India and analysed the impact on regional economic growth. They calculated a composite Infrastructure Development Index (IDI) by considering various infrastructural parameters using a simple multivariate method. Gosh et al. (2002) have developed a spatial decision support system for planning health and education infrastructure for Ranchi district. They calculated indices for education and medical facilities. The weights for the facilities are calculated using principal component analysis and the areas were prioritised for proper planning of infrastructure.

From the above research studies, it is understood that the prioritization of rural areas is a scientific method for spatial planning and allocation of infrastructural facilities. It is also seen that, number of methods are available to calculate weights for the infrastructure and to develop a decision support system for infrastructure facilities. The focus of the present paper is the development of FI methods such as Weighted Index Method (WIM) and GRA for ranking of villages. The ranked facility index value is used to prepare plans for rural development clusters in geospatial environment.

2. Methodology

The methodology adopted to carry out the present work is shown as flow chart in figure 1. The work carried out in the paper has been divided into four stages. Stage one comprises of database preparation. Database preparation is the most important and crucial part of the entire work. Spatial and non-spatial data is required for preparing the database. Spatial data includes the geographical location data of the available infrastructure.

The spatial data of the infrastructure is collected using Trimble Geo XMS Global Positioning System (GPS) instrument. The data collected using GPS instrument has been converted into geospatial feature layer as ESRI Shapefile. The accessibility to these infrastructures in terms of distance is also calculated. Similarly, the base map of the study area has been prepared in ArcGIS environment. The non-spatial data are the attributes of the feature layers. Both the spatial and non-spatial data are integrated in GIS environment. Stage two constitutes the calculation of weights for the infrastructure and prioritizing villages. Prioritization of villages based on the available infrastructure is carried out by many methods. The generally used methods are WIM, Factor Analysis (FA) and Principal Component Analysis (PCA). These are used to calculate the weights of the infrastructure. In this study, in addition to WIM, a statistical method called entropy is also used for calculating the weights. With the weights obtained, FI is calculated and the villages are ranked using WIM and GRA methods. This completes the second stage of the work. The analysis of the results obtained from the two different methods is carried out in the third stage. In the fourth stage, the ranks obtained for the villages from the two methods are spatially analysed. Depending on the spatial distribution, clustering of villages is carried out and the facilities that are not available in the cluster are proposed for planning and development. This completes the fourth stage of the methodology.

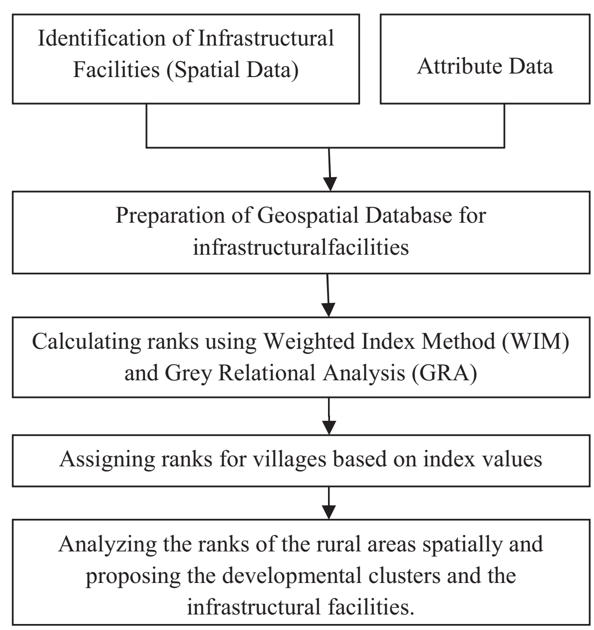

Figure 1: Methodology adopted for the present study

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3. Governing equations for facility index methods

In the present paper, weights for the infrastructure are calculated using general WIM and entropy methods. The weights obtained from entropy are used in GRA for prioritization of villages. The results obtained from GRA are compared with the WIM method.

3.1 Weighted Index Method (WIM)

In WIM, group of villages are considered as a block. The weights and the index are calculated in WIM using following equation (Garg, 2008):
If $I_i$is the index of particular function 'f' of i^{th}habitation then:

$$I_i = \sum_{j=1}^{n} W_j \times X_j \qquad (1)$$

whereW_j = weight of j^{th} parameter and it is calculated as W_j = total number of villages in block / villages having j^{th}parameter and X_j = value or the availability of j^{th}paramters in i^{th}habitation. n is the number of parameters or facilities available in i^{th} habitation.

3.2 Grey Relational Analysis (GRA):

GRA is multi objective decision making approach for prioritization of output responses. The weights for GRA are calculated using a statistical method called entropy. There is an option of choosing equal weights to the infrastructure but since, the present study mainly focuses on the relative importance of the available infrastructure entropy method is used. Entropy is a statistical method used for weightage analysis. After the values are normalized to 0 to 1 scale, 1 being the best solution and 0 being the worst solution, the difference of the values obtained from the best solution and their relative deviation is measured by adopting set of mathematical formulas which will give the uncertainty and the degree of deviation. Finally, comparing the deviation for each attribute calculates the relative importance among all the attributes.

The calculation of weights in entropy method is carried out using following equations (Kun et al., 1998)
The steps adopted are as follows:

i. Normalization:

Larger-the-Better:

$$x_i^*(k) = \frac{x_i^0(k) - min\, x_i^0(k)}{\max x_i^0(k) - \min x_i^0(k)} \qquad (2)$$

Smaller-the-Better:

$$x_i^*(k) = \frac{\max x_i^0(k) - x_i^0(k)}{\max x_i^0(k) - \min x_i^0(k)} \qquad (3)$$

where$x_i^*(k)$ is the normalized value after the gray relation generating process and$\min x_i^0(k)$, $\max x_i^0(k)$ denotes the minimum and maximum of $x_i^0(k)$ respectively.

ii. Calculating the weights using entropy

Each attribute's summation value is computed for all sequences, D_k

$$D_k = \sum_{i=1}^{m} x_i(k) \qquad (4)$$

The normalization coefficient K is computed using following expression

$$K = \frac{1}{(e^{0.5}-1)n} = \frac{1}{0.6487n} \qquad (5)$$

where$n$ represents the number of quality characteristics, or attributes. Entropy for the specific attribute e_k may be calculated using the following expression:

$$e_k = K \sum_{i=1}^{m} W_e(Z_i) \qquad (6)$$

$$W_e(x) = \left(Xe^{(1-x)} + (1-x)\, e^{x} - 1\right) \qquad (7)$$

$$Z_i = \frac{x_i(k)}{D_k} \qquad (8)$$

The total entropy value, E is computed using the following equation:

$$E = \sum_{k=1}^{n} e_k \qquad (9)$$

The relative weighting factor, λ_k, is determined by

$$\lambda_k = \frac{1}{n-E} |(1-e_k)| \qquad (10)$$

After calculating the weights using entropy method, gray relational grade is calculated using GRA. The equations adopted for calculating the grade can be seen in Kuo and Che (2010). Villages are ranked based on the calculated gray relational grade. The gray relational coefficient (Γ_j) is calculated by using the following equation

$$\Gamma_j = \frac{\Delta_{min} + \Delta_{max}}{\Delta j' + \Delta_{max}} \qquad (11)$$

4. Study area

The present study is the part of the research project to develop a rural information system with high resolution geospatial database for Geesugonda mandal, Warangal district, Telangana, India. Figure 2 shows the location of study area. The study area has an areal extent of 152 km^2 and falls between 17° 52′ North and 18° 02′ North latitudes and 79° 36′ East and 79° 48′ East longitudes. The terrain of the study area is gently

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undulating with elevation varying from 220 m to 323 m. Food crops and commercial crops like rice, pulses, cotton, red chilli and turmeric crops are grown in this region. This mandal comprises of 25 villages with overall population of 72,479. Some of the villages in the mandal do not have proper road connectivity. Scarcity of drinking water, lack of access to sanitation facilities and other socio-economic issues proves to be challenging in certain villages of this mandal (Navatha et al., 2014). Thus, there is a need for integrated development plans for the mandal to provide various infrastructure facilities within the villages. The administrative map of the mandal is shown in figure 3. The available infrastructure in the study area is shown in figure 4.

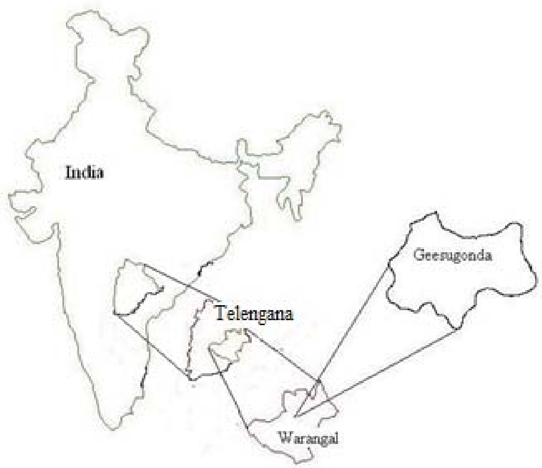

Figure 2: Location map of the study area

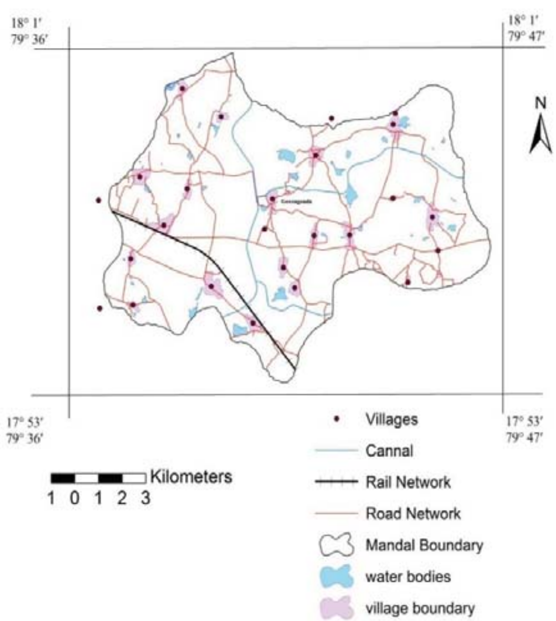

Figure 3: Administrative map of the Geesugondamandal, Warangal district

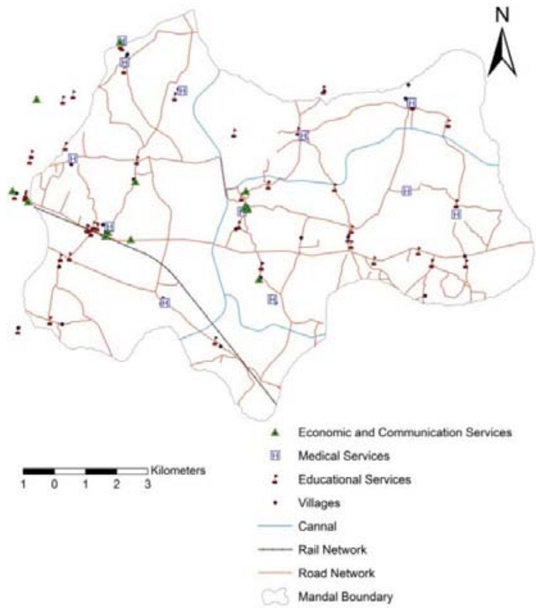

Figure 4: Infrastructure available in the study area

5. Index calculations

Thirteen parameters have been considered for index calculations which includes infrastructure related to education, health, communication and electronic connectivity. The availability of infrastructure in the villages is shown in table 1. In entropy method, weights are calculated such that the sum of the weights is equal to one. The weights obtained from entropy are used in calculating indices in GRA. For calculating ranks based on availability the location and the number of infrastructures available have been considered. The shortest distances to the nearest infrastructure for the villages are tabulated and are used to calculate the ranks using GRA method based on accessibility. The weights obtained based on availability and accessibility of infrastructure using WIM and entropy method are shown in table 2. The ranks obtained using WIM and GRA based on availability and accessibility of infrastructure is shown in table 3.

6. Analysis and planning of infrastructural facilities

Planning of infrastructure based on the ranks alone is not a correct method as spatial variation of the availability of these infrastructures also plays an important role. The ranks obtained for each village is shown spatially and the planning for the distribution of these facilities has been carried out. In order to find out the ranks which can be used for proposing infrastructure facility, the ranks obtained based on accessibility and availability of the infrastructure are spatially displayed. Figure 5 shows the ranks obtained based on availability of the infrastructure using WIM and GRA. The spatial variation of ranks obtained based on accessibility of the infrastructure using GRA method is shown in figure 6. In order to find out the ranks that have to be considered for clustering the villages, prioritization of villages based on accessibility to infrastructure is also carried out. The ranks obtained from prioritizing the villages accessibility to infrastructure is cross verified by conducting filed survey for the highest and least rank. Prioritization of villages based on accessibility to infrastructure using WIM method is not appropriate to be considered because, in WIM method, the weights and ranks are calculated based on the number of facilities available. Hence, for clustering the villages the ranks obtained using GRA method has been considered.

After studying the spatial distribution of the facilities available and the ranks obtained it is proposed to plan three development clusters in RAU. A group of villages are selected to form a cluster and the facilities are provided in the cluster so as to improve the living conditions of the rural people, which is the main aspect of PURA (Kalam and Singh, 2011). The clusters are formed based on the spatial access between the villages. In the present work, three to four villages are combined to form a cluster and the cluster comprises of both high ranked and low ranked villages. A buffer zone of 3km is taken from the high ranked villages, and the villages' covered by the buffer zone are combined with the high ranked village to form a cluster. The facilities which are not available in the cluster are proposed so as to have effective utilization of resources. The information of the clusters, the villages in the cluster and the facilities which are not there, and are to be provided to the cluster of the villages are briefly discussed below. The proposed clusters with the available road network and the villages falling in the cluster are clearly shown in figure 7.

Table 1: List of available infrastructure in the villages of study area

Name of the village	Primary school/ middle school	High school	Vocational/ degree college	Health centres	Maternity and child welfare centres	PHC	Vetern arycent res	Market centre	Police station	PO	Banks	Co Op. Soc.	Mee-seva
Kommala	1	1	0	1	3	0	1	0	0	0	0	0	0
Mogilicherla	1	1	0	1	4	0	1	1	0	0	0	0	0
BodduChintalapalli	1	0	0	1	2	0	0	0	0	0	0	0	0
Potharaojupalli	1	0	0	0	1	0	0	0	0	0	0	0	0
Darmaram	1	1	2	1	3	0	1	0	0	1	1	0	1
Vanchanagiri	1	1	0	1	3	0	0	0	0	0	0	1	0
Vasanthapuram	1	0	0	0	2	0	0	0	0	0	0	0	0
Shayampeta	1	1	0	0	3	0	0	0	0	0	0	0	0
Geesugonda	4	1	0	1	6	1	1	0	1	1	1	1	1
Konaimakula	1	0	0	0	1	0	0	0	0	0	0	0	0
Machapuram	1	1	1	1	3	0	1	0	0	0	1	0	0
Gangadevipally	1	1	1	0	1	0	0	0	0	0	0	0	0
Manugonda	1	0	0	1	2	0	0	0	0	0	0	0	0
Elkurthi	2	1	0	1	5	0	1	0	0	0	0	1	1
Mariyapuram	0	0	0	0	1	0	0	0	0	0	0	0	0
Ukhal	1	0	0	1	1	0	1	0	0	0	1	1	0
Stambampalli	1	1	0	0	2	0	0	0	0	0	0	0	0
Vishwanathpuram	0	0	0	0	2	0	0	0	0	0	0	0	0
Gorrekunta	1	1	0	1	6	0	0	0	0	0	0	0	0
Anantharma	1	0	0	0	1	0	0	0	0	0	1	0	1
Chandrayapalli	1	0	0	0	1	0	0	0	0	0	0	0	0
Duupakunta	1	0	0	0	2	0	0	0	0	0	0	0	0
Arepalli	0	0	0	0	1	0	0	0	0	0	0	0	0
NandanayakTanda	4	0	0	0	5	0	0	0	0	0	0	0	0
Janpaka	2	0	0	0	1	0	0	0	0	1	0	0	0

PHC: Primary health centre
Co. Op. Soc.: Cooperative society
PO: Post office / telegraph

Table 2: Weights of the infrastructure obtained from WIM and entropy methods

Infrastructural Facilities	Obtained Weights		
	WIM	Entropy (availability)	Entropy (accessibility)
Primary school/middle school	1.136	0.067	0.025
High school	2.272	0.068	0.023
Vocational/ degree college	8.333	0.077	0.086
Health centres	2.272	0.068	0.033
Maternity and child welfare centres	1.000	0.067	0
Primary health centers	25.000	0.095	0.120
Veternary carters	3.571	0.069	0.054
Market centre	25.000	0.095	0.209
Police station	25.000	0.095	0.118
Post office / telegraph	8.333	0.075	0.088
Banks	5.000	0.071	0.078
Cooperative society	6.250	0.073	0.071
Mee-seva	6.250	0.073	0.091

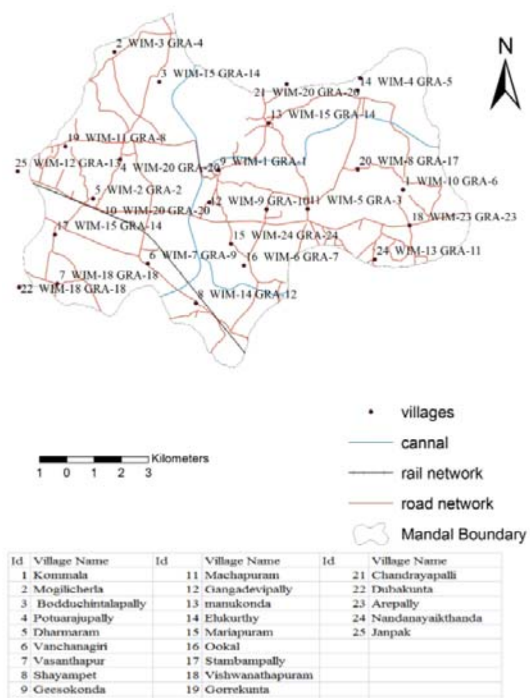

Figure 5: Spatial distribution of the ranks obtained based on availability of infrastructure using WIM and GRA methods

Table 3: Ranks obtained from WIM and GRA based on availability and accessibility toinfrastructure in study area

Sl. No.	Villages	GRA availability	GRA accessibility	WIM availability
1	Kommala	6	20	10
2	Mogilicherla	4	22	3
3	BodduChintalapalli	14	14	15
4	Potharaojupalli	20	11	20
5	Darmaram	2	1	2
6	Vanchanagiri	9	8	7
7	Vasanthapuram	18	21	18
8	Shayampeta	12	17	14
9	Geesugonda	1	2	1
10	Konaimakula	20	3	20
11	Machapuram	3	10	5
12	Gangadevipally	10	9	9
13	Manugonda	14	13	15
14	Elkurthi	5	15	4
15	Mariyapuram	24	4	24
16	Ukhal	7	6	6
17	Stambampalli	14	5	15
18	Vishwanathapuram	23	23	23
19	Gorrekunta	8	7	11
20	Anantharam	17	18	8
21	Chandrayapalli	20	19	20
22	Duupakunta	18	25	18
23	Arepalli	24	16	24
24	NandanayakTanda	11	24	13
25	Janpaka	13	12	12

1. Kommala cluster

The villages falling into this cluster are Anantaram, Vishwanathapuram, NandanayakTanda and Kommala. In these villages Kommala is the village which is spatially covering with a buffer of 3 km to the other villages mentioned in the cluster. The village also have all the facilities which can be accessed by the other villages because of the availability of proper road connectivity. The facilities needed for the cluster are a college, post office, co-operative society, police station and a market centre. These are the facilities that are to be provided in the Kommala cluster. Even though Kommala village does not have bank and Mee-sevacenters, they are available in Anantharam and they can be accessed by other villages in the cluster.

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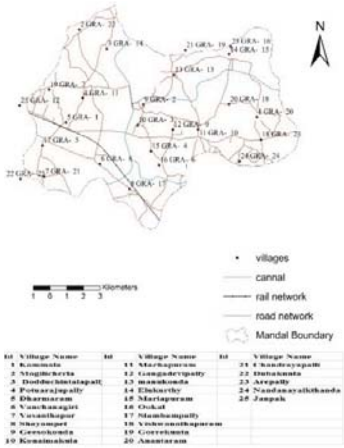

Figure 6: Spatial distribution of the ranks obtained based on accessibility to infrastructure using GRA method

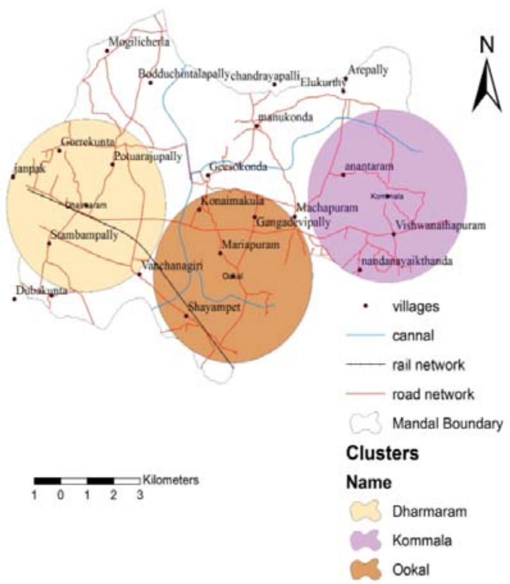

Figure 7: Proposed clusters and the connectivity with villages

2. Dharmaram cluster

The villages in this cluster are Janpaka, Gorrekunta, Poturajupalli, Stambampalli, Dharmaram. Dharmaram is the village which is spatially covering the above villages with a 3 km buffer. It is the biggest cluster which covers around five villages. Dharmaram is the main village which is ranked in second place and also has all the facilities. The facilities which are to be provided are police station, market centre and primary health centre. Dharmaram is a developed village which has all the infrastructural facilities. The main advantage of providing the infrastructure facility is that, this village is located near to state highway and is easily accessed by any village. Though village Vanchanagiri is not under the buffer of the Dharmaramcluster, it is very near to the cluster and hence can access the facilities that are available in the cluster.

3. Ukhal cluster

Konaimakula, Gangadevipally, Mariyapuram, Shayampeta, Ukhal are the villages combined under this cluster. Ukahl can be the cluster head village since Ukhal has all the facilities. The facilities that have to be provided are primary health centre, market centre, post office and Mee-seva centre. The only disadvantage with Ukhal is that it is not located near to state highway.

With the proposed three clusters, 15 villages will be benefited if the facilities that are needed are provided in the cluster. Based on the spatial distribution of villages it is seen that, the least ranked village Arepally is at a distance less than 3 km from the high ranked village Elkurthy. Hence, the people of the village of Arepally can easily access all the facilities that are available in Elkurthy. Similarly, facilities in Mogilicherla can be accessed by people in Bodduchintalapally since it is spatially distributed at a distance less than 3 km. Manugonda and Chandrayapalli are located near to the mandal head quarter, Geesugonda and can be accessed easily through the road network. Bodduchintalapally village is also properly connected with Mogilicherla and the facilities available can be easily accessed. The villages that are remaining are Vasanthapur and Dupakunta. These villages are spatially located near to Dharmaram village, but are a bit away from the cluster. It is not economical to propose all the facilities to the villages, it is planned to propose the educational and medical facilities which are very essential. A health centre and a high school can be established in any of the village to have better education and medical infrastructure.

The market centre is located in Mogilicherla, which is accessible to all the villages by road connectivity. It is proposed to provide mini market centres in the clusters which are very useful for the farmers to sell their products and it is economical. Instead of individual police stations, police check posts can be provided for each cluster.

7. Conclusions

Present paper focussed on the planning of infrastructural facilities based on their spatial distribution and ranking based on the index value. The developed methodology has been applied to Geesugondamandal, Warangal district, Telangana, India. The villages have been ranked based on the accessibility and availability of the infrastructure. The facilities have been given weights which are calculated using WIM. Entropy, a statistical weighing method is also used for calculating weights of the infrastructure. The weights obtained are used for calculating the ranks. The ranks are calculated using WIM and GRA method. For providing infrastructure, it is necessary to consider the prioritization of villages based on availability and accessibility. It is observed that GRA method gives best results when the prioritization of villages based on accessibility and availability. This is because of the limitation of WIM method as it considers only the availability of the facilities and not the accessibility. The ranks obtained by villages from GRA method based on accessibility differ with the ranks obtained from GRA method based on availability and WIM method based on availability. Geesugonda got rank 2 in GRA method based on accessibility and got rank 1 in other methods. Village Geesugonda has got the highest rank as anticipated owing to the availability of all infrastructure. The only disadvantage with the Geesugonda village is that it is not located near the state highway.Mariyapuram village got rank 4 from GRA method based on accessibility and got rank 24 in other methods. This is due to the accessibility of this village to all the infrastructural facilities even though it does not have important facilities.

Based on the spatial distribution of villages and the ranks obtained by them, three clusters have been designed for the effective use of infrastructure. The infrastructure which is not available in the clusters is proposed for the respective clusters. This is the effective method for proper planning, maintenance and execution of infrastructural facilities in rural areas. Approach proposed in this paper, can be used by planners, government officials and the local people for development of rural areas. Proposed method can also be used for selected rural administrative blocks under PURA model.

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