Identification of the Spatial Distribution of Environmental Development Needs using GIS

- A Study of Polonnaruwa District, Sri Lanka

N. T. S. Wijesekera, H. H. Leelananda, S. U. B. Jayamaha and S. De Silva

In a developing country like Sri Lanka, it's very important to plan and manage its development programmes in a rational manner ensuring optimum use of resources. Therefore, a decision maker has to carry out spatial prioritization to manage the scarcity of resources, while identifying the desires of the rural community. In this context, GIS provides a tool for the managers to identify the spatial distribution of requirements and then to make a comparison of presently deployed resources to make rational decisions through Environmental Development Needs Assessment Programmes. The present work is on the development of a GIS for the Polonnaruwa District to identify the spatial distribution of Environmental Development Needs. A household survey was conducted including approximately 31,000 households out of a total of 91,000. The survey assessed the desirable environmental development needs for self-development and also for the village development. A vector-based GIS model was developed to compute the spatially aggregated priority GN and the DS divisions. Survey responses for development needs were analysed considering the number of responses and the associated stakeholder priorities. GIS data layers were prepared to reflect the priority needs for the district. Ratio Estimation Procedure was used to compute the weights for the aggregation of development need options for the identified spatial extents. For individual family development, the top priority was the need of a housing unit whereas in case of needs to develop one's own village the topmost request was to obtain electricity supply. The study indicates the potential of GIS to identify the spatial distribution of EDN based on each GND thereby facilitating a resource manager to carry out rational management of development assistance.

Key Words: Sri Lanka, Polonnaruwa, GIS, Model, Environmental, Development, Overlay, Stakeholder Assessment, Planning, Management

1.0 Introduction

In a developing country like Sri Lanka, it's very important to plan and execute its development programmes in order to suitably manage valuable resources to ensure the fulfilment of public aspirations. Sri Lanka being a developing country has significant room for enhancement of living standards of its nationals and this is more so in the case of rural areas. There are critiques who indicate that insufficient attention had been given to the needs of rural area community when launching and executing rural development projects. In this backdrop, a decision maker has to carry out prioritization to suitably utilize the scarce resources, while identifying the desires of the rural community. Prioritisation of resources allocation requires spatial assessments. Therefore, to identify the spatial resource mobilization needs, it is necessary to carry out a stakeholder needs assessment at a suitable spatial resolution.

Though the spatial unit of assessment can be as fine as household level, the location identification with household coordinates would require an enormous amount of time and financial resources. The next level would be to identify the needs at village level. As such the administrative unit of Grama Niladhari Division (GND) would be the next best representative spatial unit.

Geographic Information System (GIS) provides a tool for managers to identify spatial...
distribution of resources requirements and then to make a comparison of presently deployed resources. Therefore, Development Needs Assessment Programmes could effectively utilize GIS to make rational development planning decisions (Barros, Maseda, and Rivera 2008, Weerakoon 2002).

The present work is on the development of a GIS to identify the spatial distribution of results identified through an Environmental Development Needs Assessment (EDNA) programme carried out for the Pollonnaruwa District (Map 1). The paper describes the environmental development needs assessment, and the development of a GIS model using ArcGIS. The main objective of the work was to identify the stakeholder perspective of environmental development needs in a geographically distributed manner and identify priority spatial extents in order to provide information for appropriate decision making.

The specific objectives were to:
1. assess the needs of the stakeholders for self development,
2. assess the needs of the stakeholders for the development of their village,
3. develop a geographic information system enabling the assessment of above needs in a spatially distributed manner and
4. prioritise and assess the needs in relation to administrative boundaries enabling suitable decision making.

2.0 Study area

The study area was taken as the Pollonnaruwa District which is in the North Central Province and located between longitudes 81° 0’ East, and Latitudes 7° 56’ North. The city of Pollonnaruwa is approximately 260 kilometers away from Colombo. Sri Lanka’s average population percentage below the poverty line (Head Count Index) is 23%. The Pollonnaruwa District Head Count Index is 24% with an approximate number of 89,000 persons falling into this category (Census 2002). The district consists of the seven different Divisional Secretariat Divisions (DSD) and 295 Grama Niladhari Divisions (GND) with an area of 3472 Sq. Km. The total population of Polonnaruwa District counted to 358,984 (Census 2001) having a density of approximately 117 persons per square kilometre (Map 2). The male population of 187,789 indicated a marginal difference when compared with the females. The total number of households were 91,000. Land cover maps prepared with the use of 1:50,000 topographic maps showed that the predominant type is forest while paddy is the next major type. This reflects that the agriculture, either irrigated or rainfed is influencing the living patterns of the population in the district (Map 3).
3.0 Methodology

The assessment of environmental development needs according to the stakeholder perspectives was based on a questionnaire survey. Investigation of stakeholder interests, characteristics and circumstances were taken into consideration while designing the questionnaire to arrive at an understanding of issues within a systems context (Grimble 1998). Initial preliminary discussions were held with the divisional authorities, local politicians, administrators and general public, to identify important aspects for data collection. Having recognized the importance of identifying the existence of a significant variation in stakeholder opinions (Baggett, Jefferson and Jeffery 2008) special attention was given to this aspect. During discussions, it was noted that stakeholder groups did not possess divergent views on key areas that were to be developed. Therefore, the options in questionnaire sections covering self and village development needs were designed to provide a listing where each stakeholder ranked according to preference. Questionnaire listings were made quite comprehensive within each cluster, as the stakeholder interests had to be indicated in a specific manner to effectively capture stakeholder preference. After preliminary information collections a survey questionnaire was developed and tested. The questionnaire developed in Sinhala language considering the capabilities of the stakeholder community consisted of seven major aspects of data collection. The data capturing efforts to identify needs and propose solutions included, 1) family details, 2), details of the chief of household 3), family employment details, 4), Debt details, 5), Debt Settlement Plans, 7) Priority development needs pertaining to the village in common, and 6) Priority needs for self household development. Other than the above details, geographic information pertaining to Grama Niladhari Division, names and signatures of Grama Niladhari and Chief Occupant of the household were collected. The questionnaire which was designed to be filled by the Chief Occupant carried two pages of instructions out of a total of 5 pages.

Data collected were first entered into a database created using MS Access and Visual Basic which consisted of a data row for each questionnaire. Data entry formats were prepared to easily incorporate each data in the GIS with detailed data of each household as attributes. Each questionnaire was given a unique identity number to facilitate easy data checking. After computing summary statistics of survey data using a statistical software, database was then migrated to the off-the-shelf Geographic Information System software ArcGIS. GIS utilised the spatial data aggregated in each Grama Niladhari Division to identify the spatial variations through appropriate classification, reclassification and overlay operations.

Survey responses for development needs were analysed considering the number of responses and the stakeholder priorities indicated for each of the selected development needs. The priority needs for the district were identified and then the requests corresponding to the population in each GN were computed and classified to form GIS data layers showing the spatial variation and a priority indication based on the number of requests in each spatial unit. The classification filter used to assess stakeholder responses assumed a five class stepped function having ranges as Super Primary, Primary, Secondary, Tertiary and Normal to assess all stakeholder responses. District level
aggregation of responses received for each environmental development need were used to assign normalised weights for the Ratio Estimation Procedure (Malczewski 1999). An overlay GIS model (Figure 1) was developed to compute the aggregated priority GN divisions and the DS divisions in the entire district. \( R_j \) which is the aggregated priority rating of a GN\(_j\), and \( R \) which is the spatial aggregation over a DS division were computed using the model for both Development Need responses.

\[
R_j = \sum_{i=1}^{n} \varphi(SR_i) \cdot w_i
\]

\[
\hat{R} = \frac{\sum_{j=1}^{k} A_j R_j}{\sum_{j=1}^{k} A_j}
\]

\( R \) and \( R \) representations given above, the suffixes \( i, j \) denote the development need, and the GN division respectively. The Number of Development needs is taken as \( n \) and \( k \) is the number of GN divisions in the particular DS. \( SR \) is the Number of stakeholder responses and \( A \) is the area of the respective GN division. \( \varphi \) is the classification function that rank the strength of the stakeholder responses. \( w \) is the normalised weight assigned to each development need.

4.0 Data and Data Collection

Survey team included Grama Niladhari(GN) Officials, Divisional Secretariats of the area to achieve the collection of data pertaining to 31,591 households (Map 2). Except for two GND all other GND participated with significant contributions. An approximate average of 4500 households from each DSD contributed to the survey. The minimum participation was 2750 from Elahera DSD. Questionnaires prepared were tested with sample communities and also with the Divisional Secretaries to ensure the clarity and completeness of the options incorporated for assigning priority levels. The survey data collection was completed in less than one month.

Since the main objective of stakeholder survey was to identify the environmental development needs of the district, the spatial distribution of self and village development needs of each household were incorporated into the GIS in a very detailed manner. GIS data were primarily from the 1:50,000 toposheets. Pollonnaruwa District GN boundaries pertaining to 295 units were obtained from the Agriculture Development Ministry, Population and Household data were taken from the Department of Census and Statistics Web site. The spatial boundary data posed many problems with the names, alignment and boundary matching. GIS data were checked for accuracy and then processed to prepare GIS maps. Collection of available data, collecting supplementary data, data cleaning, data modelling, overlay and layout generation (Kaijuka 2007) were suitably carried out to create GIS maps for decision making. (Yeung 2005, Longley et al., 2001. Divisional Secretary and Grama Niladhari boundaries. Main towns and villages, main roads, forest cover, paddy lands, water bodies, population density are some of the layers which were taken as base datasets.

5.0 Analysis and Results

5.1. General

Survey results indicated that the average distribution of nationality in the Polonnaruwa district consisted of 91.7% Sinhalese, 1.6% Tamil, 6.6% Muslim and 0.1% others. Lankapura DSD had a Muslim percentage of 23 while the Tamil population in Welikanda DSD was 10%. The average distribution according to the religion was 90.9% of Buddhists, 6.6% of Islam, and 1.5% of Hindu. Each 23% Islam in Lankapura DSD, 9% Hindu in Welikanda DSD and 2% Christian in Hingurakgoda DSD were notable variations.

Families with female household heads were 14.2% and the marital status data revealed that 13% of the household heads were either a widow or a widower. With regards to the
education status, it was revealed that a majority of 37% household heads were of the group having an education to a stage between Grade 6 and 9. 64.1% of the household heads had received primary level education.

According to the survey data approximately 49% of the population in Polonnaruwa District are farmers; 16.4% are daily paid labourers; another 5.7% are self-employed; and 10.6% are government employees. Unemployed component is 7%. Welikanda DSD with 66.7%, Dimbulagala DSD with 66.8% have shown highest percentages of farmers. The highest unemployment of 10.3% is at Tamankaduwa DSD.

The household heads had indicated that most of their loans had been taken for agricultural purposes. The number of households amount to 47.6% of those who had resorted to loans. Loan amounts of 55.6% of the households had not exceeded 20,000.00 rupees. 44.5% of the loans are from the recognized banks and the Samurdhi Bank loans had amounted to 20.4%.

5.2. District and DSD Development Needs

Stakeholder priority responses received for each of the development needs pertaining to own households, were tabulated for the entire district (Table 1). In this table, each column represented a particular development need which was indicated as an option in the questionnaire. Data rows indicated the priority order as filled by each respondent and in the ascending order.

Data rows indicated the priority order as filled by each respondent and in the ascending order. Therefore, each cell in table represented cumulative responses for the entire spatial extent corresponding to a particular development need and a priority indicator. The maximum responses received by each development need was computed to arrive at the Community Priority Order for that spatial extent. The simple concept that any preferences received by a particular option would be maximum responses received by each option having higher ranks, in case those higher options were not available, was used. Accordingly, in the computation of community priority to a given alternative was computed as follows. Initially, the development alternative that received the maximum responses was identified along with the corresponding priority rank. The maximum indicated the rank of a particular development need that received the highest stakeholder agreement. The analysis of survey responses shows that all priority stakeholder responses that were indicated for development needs which were listed above this rank also indicates a chief occupant’s liking for the maximum ranking development need, in case there is a situation where those options are not available.
Table 2: Priorities of Household Development Needs for Pollonnaruwa District

| Priority | Responses | %  | Development Need                                      |
|---------|-----------|----|------------------------------------------------------|
| 1       | 22768     | 72.0% | Acquisition of Support for Own House Unit Q 6.F3     |
| 2       | 20506     | 64.9% | Enhancement of Family Income Q 6.F1                  |
| 3       | 14442     | 45.7% | Enhancement of Funds for Self Employment Q 6.F4      |
| 4       | 10768     | 34.1% | Enhancement of Health Facilities Q 6.F2              |
| 5       | 10276     | 32.5% | Enabling Training for Self Employment Q 6.F5         |
| 6       | 6994      | 22.1% | Enabling Permanent Employment Opportunities - Children Q 6.F6 |
| 7       | 3125      | 9.9%  | Provision of Land for the Second Generation Q 6.F7   |
| 8       | 2845      | 9.0%  | Removal of the Difficulties in Obtaining Samurdhi Relief Q 6.F8 |
| 9       | 1883      | 6.0%  | Enhancing Local Job Opportunity for a Family Member Q 6.F9 |
| 10      | 879       | 2.8%  | Enhancing Foreign Jobs Opportunity - Family Member Q 6.F10 |
| 11      | 756       | 2.4%  | Ensuring an Agro Well for Cultivation Q 6.F11       |
| 12      | 485       | 1.5%  | Enabling Scholarships for Education Q 6.F12         |
| 13      | 475       | 1.5%  | Enabling Opportunities for Continuing Education Q 6.F13 |
| 14      | 408       | 1.3%  | Improving availability of Drinking Water Q 6.F16     |
| 15      | 378       | 1.2%  | Enabling Harvest Enhancement Mechanisms Q 6.F18      |
| 16      | 374       | 1.2%  | Facilitating Relief for Land Ownership Problems Q 6.F15 |
| 17      | 360       | 1.1%  | Enabling Reasonable Sale of Paddy Harvest Q 6.F17    |
| 18      | 295       | 0.9%  | Provision of a Cooperative Society for essential Food Q 6.F14 |

for selection. This assumption is valid for a situation where the ranks are listed in a descending priority order. Therefore, the maximum responses received for each development option was computed by adding the maximum responses to all other priority responses above the maximum priority rank.

Table 2 shows the Community Priority of the entire district received for each development need pertaining to their own household. In the same manner, the priority development needs corresponding to each of the DSD were calculated. The same methodology was used to compute the community priority for the Village Development Needs (Table 3 and 4).

5.3. Spatial Distribution of Development Needs

GIS data layers were developed to identify the spatial distribution of each development need that received priority in the district. These represented the spatial variation of stakeholder requests for that particular development need. In this effort, the first ten development priorities were identified and for each need, the spatial distribution was plotted by considering the number of requests per GND. Family member details available in the survey data were used to convert the responses by each household to responses pertaining to population over 18 years in a particular GN. Thereafter, priority requests were classified by a function identified using the data of population in a GN division. Classification of requests for each development need as Super Primary, Primary, Secondary, Tertiary and Normal were corresponding to requests for that development need and falling into the groups, >80%, 50-80%, 10-50%, 5-10% and <5% of population respectively. Spatial variation of priority classes for "Acquisition of Support for Own House Unit", which is the Priority number one for Polonnaruwa District, is plotted in relation to GN divisions and shown in Map 4.

Similar data Layers were prepared for each of the top ten
Table 3: Stakeholder Responses for Village Development Needs and Identification of Community Priority

| Community Development Needs | Court | Count | Court | Count | Court | Count | Court | Count |
|-----------------------------|-------|-------|-------|-------|-------|-------|-------|-------|
| Electricity for Village (Q7V4) | 1026 | 1329 | 201 | 596 | 913 | 550 | 400 | 357 |
| Water Supply for Households (Q 7.8) | 18.63% | 26.33% | 30.59% | 37.79% | 11.49% | 9.47% | 0.09% | 913 |
| Water for Paddy Cultivation (Q 7 V 7) | 157 | 711 | 1993 | 616 | 378 | 463 | 400 | 357 |
| Electricity for Part of the Village (Q 7 V 5) | 134 | 130 | 105 | 105 | 14 | 23 | 28 | 24 |
| Lack of Teachers in Primary Schools (Q 7 V 15) | 17 | 22 | 45 | 73 | 9 | 27 | 27 | 31 |
| Establishment of Agricultural Advisory Center (Q 7 V 22) | 14 | 15 | 15 | 15 | 4 | 2 | 2 | 2 |
| Solution to Solid Waste Disposal (Q 7 V 24) | 14 | 15 | 15 | 15 | 4 | 2 | 2 | 2 |
| Improvement/ Rehabilitation of Byroads (Q 7 V 14) | 7 | 9 | 12 | 12 | 3 | 3 | 2 | 2 |
| Lack of Road Transport Services (Q 7 V 28) | 7 | 9 | 12 | 12 | 3 | 3 | 2 | 2 |

Table 4: Priorities of Village Development Needs for Pollomaruwa District

| Priority | Responses | % | Development Need |
|----------|-----------|---|-----------------|
| 1        | 16313     | 51.63% | Electricity for Village (Q7V4) |
| 2        | 13360     | 42.29% | A Village Institution for the Selling of Paddy (Q 7 V 1) |
| 3        | 13286     | 42.05% | Electricity for Part of the Village (Q 7 V 5) |
| 4        | 1831     | 37.79% | Concessionary Telephone Service (Q 7 V 6) |
| 5        | 9665      | 30.59% | Water for Paddy Cultivation (Q 7 V 7) |
| 6        | 8318      | 26.33% | Water Supply for Households (Q 7.8) |
| 7        | 7941      | 25.14% | Market for Village Agricultural Products (Q 7 V 2) |
| 8        | 5886      | 18.63% | Transport Facilities During Day Time (Q 7 V 9) |
| 9        | 5751      | 18.20% | Establishment of a Vocational Training Institute (Q 7 V 3) |
| 10       | 4631      | 14.66% | Transport Facilities During Night Time (Q 7 V 10) |
| 11       | 3629      | 11.49% | Safeguarding Crops from Elephants (Q 7 V 11) |
| 12       | 3351      | 10.61% | Improvement/Rehabilitation of Bus Routes (Q 7 V 13) |
| 13       | 2991      | 9.47% | Cultivation Problem due to Terrorists (Q 7 V 12) |
| 14       | 2082      | 6.59% | Lack of Teachers in Primary Schools (Q 7 V 15) |
| 15       | 1857      | 5.88% | Improvement/Rehabilitation of Byroads (Q 7 V 14) |
| 16       | 1667      | 5.28% | Lack of Teachers for GCE Ord Level Classes (Q 7 V 16) |
| 17       | 1223      | 3.87% | Lack of Teachers for GCE Adv Level Classes (Q 7 V 17) |
| 18       | 1149      | 3.64% | Rehabilitation of Elephant Fence (Q 7 V 18) |
| 19       | 828       | 2.62% | Low interest loans for Cultivation (Q 7V20) |
| 20       | 746       | 2.36% | Lowering of Fertilizer and Pesticide Prices (Q 7 V 19) |
| 21       | 674       | 2.13% | Establishment of Employment Generation Institute (Q 7 V 21) |
| 22       | 529       | 1.67% | Solution to Solid Waste Disposal (Q 7 V 24) |
| 23       | 502       | 1.59% | Establishment of Agricultural Advisory Center (Q 7 V 22) |
| 24       | 478       | 1.51% | Protection of Property from Flooding (Q 7 V 23) |
| 25       | 286       | 0.91% | Environmental Conservation (Q 7 V 26) |
| 26       | 114       | 0.36% | Continuing Education for School Leavers (Q 7.25) |
| 27       | 43        | 0.14% | Educational Programmes for Housewives (Q 7.27) |
| 28       | 30        | 0.09% | Lack of Road Transport Services (Q 7 V 28) |
Table 5: Allocated Weights for the GIS Overlay Model

| Computed Weights for GIS Overlay Operation | | |
|-------------------------------------------|--|--|
| Household Development Need | Village Development Need | |
| Requirement | Weight | Requirement | Weight |
| 6.1 | 0.114 | 7.1 | 0.138 |
| 6.2 | 0.153 | 7.2 | 0.082 |
| 6.3 | 0.217 | 7.3 | 0.059 |
| 6.4 | 0.241 | 7.4 | 0.168 |
| 6.5 | 0.109 | 7.5 | 0.137 |
| 6.6 | 0.074 | 7.6 | 0.123 |
| 6.7 | 0.033 | 7.7 | 0.100 |
| 6.8 | 0.030 | 7.8 | 0.086 |
| 6.9 | 0.020 | 7.9 | 0.061 |
| 6.10 | 0.009 | 7.10 | 0.048 |
| Sum | 1.000 | Sum | 1.000 |

priorities corresponding to the own household and village development needs. As indicated earlier, and based on the stakeholder responses, weights for each option was computed and the values for each development need is shown in the Table 5. Previously described GIS model was applied to identify the spatial variation of aggregated priority rating (Rj) at GN(Map 5 and Map 7) and DS (Map 6 and Map 8) division level. Computations can also be done in the GIS to summarise the details of GND in each DSD (R) which had requested a particular development need and these capabilities are extremely useful for the management of spatially distributed resource and carrying out related monitoring activities.

6.0 Discussion

Social and physical GIS data pertaining to each GN enabled the comparison of resource mobilisation needs towards meaningful development. Survey successfully collected data from 31,591 families through a structured questionnaire and with the help of the existing administration system of the government. Though there were a very limited number of inadequacies in the data collection, the effort which was completed within approximately one month could be mentioned as a great success. The survey responses were quite satisfactory and an accuracy check on the sample survey results indicated that the error level at 99% confidence was 0.6%. At a confidence level of
99% and a percentage accuracy of 5% revealed that the confidence interval was as low as 0.24 indicating the strength of the survey results (Bartlett, Kotrlik, & Higgins 2001, Lenth 2001, CRS 2007, CustomInsight 2007).

The study identified the development needs corresponding to two fundamental aspects namely the development of a "Family Household" and the "Development of the Village”. GIS facilitated identifying the spatial distribution of GND with respect to either a single or a combination of development needs, while taking the strength of stakeholder requests into consideration. This is a very important information for a resource manager as it provides the pattern of stakeholder request distribution, summary of GND with different degree of stakeholder priority, and an assessment of GND numbers of different categories in each DSD.

GIS overlay operation enabled the identification of an aggregate indicator for each GND, by considering the overall stakeholder priority indicated for each development need. Incorporation of this type of weighted layer aggregation models enable the resource managers to easily identify the priority spatial extents with regards to a desired group of development needs for the region.

GIS model also enabled spatial aggregation and the results facilitate the identification of priority DSD with respect to each development need. This summary result provides the opportunity to select the sequence in which the resources should be channelled for development activities.

7.0 Conclusions

1.0 The survey and analysis of the data with GIS enabled the identification of priority development needs in relation to stakeholder families and their villages.

2.0 The study used a simple rationalisation methodology to aggregate stakeholder prioritisation responses corresponding to each development need. This method enables the computation of an aggregated development priority indicator pertaining to a given spatial extent.

3.0 A GIS model with the capability of spatial data aggregation through overlay operations to reflect the spatial distribution of cumulative priority status through a stakeholder based indicator (Rj) was successfully developed thus providing a tool for micro level planning, implementation and management of development activities.

4.0 The GIS model enabled the computation of spatially aggregated priority indicator considering the strength of stakeholder responses pertaining to a particular spatial entity, thereby enabling a decision maker to easily manage the development efforts in the macro scale. This proves the immense potential of GIS to plan or evaluate effective resource utilization in a spatially distributed manner.

5.0 In the Polonnaruwa district the stakeholders indicated that the five most important household development needs are listed below.

i. Acquisition of Support for Own House Unit
ii. Enhancement of Family Income
iii. Enhancement of Funds for Self Employment
iv. Enhancement of Health Facilities
v. Enabling Training for Self Employment

6.0 The most requested villages development needs were indicated as the following.

i. Electricity for Village or Part of the Village
ii. A Village Institution for the Selling of Paddy
iii. Concessionary Telephone Service
iv. Water for Paddy Cultivation
v. Water Supply for Households

7.0 The Elahera DSD was identified as the priority administrative unit for family household development while the Welikanda DSD was identified as the priority unit for the villages development.

8.0 The GIS model and the associated results demonstrated in this work enables decision maker to parallely look at the development needs, the priority spatial entities and then commence the allocation of resources. This capability to carryout prioritisation facilitates a comparable assessment of local and regional development requirements and the effectiveness of already mobilised resources.
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