EXTRACTION AND MODELLING SPATIAL PARAMETERS IN GROUNDWATER POTENTIAL STUDIES IN A HARD ROCK TERRAIN, SRI LANKA

K.A.W. Kodituwakku, Deputy General Manager, Water Resources Board, Sri Lanka

KEY WORDS: Hydrology, GIS, Remote Sensing, Geostatistics

Commission VII

ABSTRACT:

Study of flow through fractured hard rocks needs geometrical properties of the fracture network as well as fracture properties such as fracture width, permeability, porosity etc. Since hard rocks (Precambrian metamorphic rocks) of Sri Lanka has undergone through polydeformations and polymetamo- rphism, in geologic history, it has very complex fracture net work system. Hence it is a difficult task to understand fracture properties, mentioned above, to use mathematical equations to study flow characteristics. To overcome this problem, Remote Sensing and GIS techniques can be used in order to model productive fractured aquifers. Some surficial features related to geology, geostructure, geomorphology and surface water bodies which may influence the yield capacities of tube wells can be detected by Remote sensing techniques. Relevant spatial parameters identified by statistical analyses of surficial features, mentioned above, together with yield capacities of deep tube wells are used as inputs to the GIS in order to model potential groundwater zones. Also it is possible to develop groundwater exploration strategies with emphasis on well location studies based on the statistical analytical results of surficial features which influence well yields.

INTRODUCTION

Sri Lanka is an Island with an area about 65,000 Km^2 and is situated southern part of Indian ocean. Three major climatic zones were identified as Dry, Intermediate and Wet zone(Figure.1). A hard rock terrain located in the intermediate zone has been selected for the detailed study. However preliminary data analysis have been based on data on more than one thousand deep tube wells drilled in the entire Kurunegala district(Figure.1) for rural water supply schemes. Since surface water remains as a major constraint to the accelerated agricultural, industrial and some settlement projects, groundwater is under consideration as an additional water source. It was found that some surficial features such as lineament (originated possibly by faults, joints, foliations etc.), valley (generally occupied by paddy cultivation in he study area), geology, geomorphology, drainage network and ancient irrigation system spread over the study area have been closely related to the yield capacities of deep tube wells drilled in the area. Hence the above mentioned surficial features can be used as surface indicators to the sub surface weathering and fracturing which are essential for currency of high yielding productive aquifers in hard rocks. Remote sensing techniques can be used to detect the above surficial features and image processing may be used for extraction of required spatial parameters which in turn have to be applied as input to the GIS. Relevant surficial features have been detected by interpretation of 1:40,000 scale aerial photographs as cloud free landsat imageries were unable to find during data analysis. The same aerial

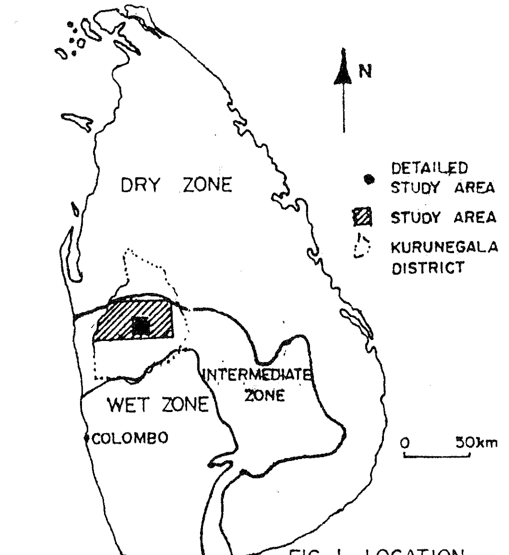


FIG · 1 - LOCATION

from deep tube wells. The model used in this study is adopted from Agterberg et.al (1988) who developed it for mineral explorations. The model demarcates zones of different groundwater potentialities on regional scale and hence it may be used to develop groundwater supply schemes for agricultural, industrial and settlement projects.

METHODOLOGY

Statistical analysis: The main objective is to differentiate the data set(on yield capacities of deep tube wells) based on climatic and hydrogeological conditions of the area. In this context, yields of about 1200 wells have been considered. The non-parametric two sample test showed that the wells located in the dry zone(900-1500mm of rain fall) and that of in the intermediate zone(1500-2300mm of rain fall) have significant different on yield capacities. Similar statistical analysis revealed that well yields during rainy period are higher than that of during dry period in the dry zone area. But such differences could not be found in the intermediate zone. Hence wells drilled in both rainy and dry period have been used for detailed statistical analysis as the detailed study area occupied within the intermediate zone(Figure1.). Further segmentation of data on well yields has been made on the basis of different geohydrological characteristics and can be described under four major groups. Measured spatial parameter which will be used for modeling is also summarized in each group and the figure2 shows the schematic representation of the measured spatial parameter.

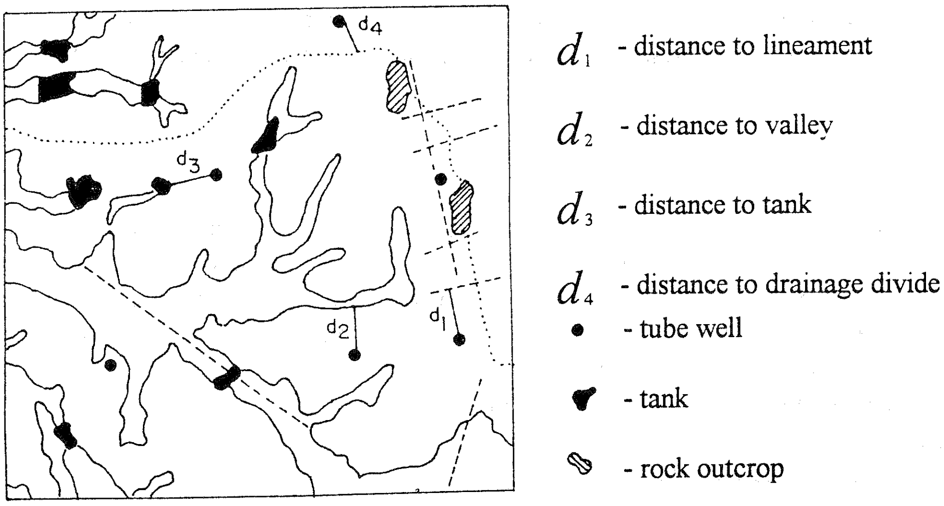


Figure 2: Spatial features and measured distances

Group 1: Wells located near to a lineament where valley is not well developed(ie. only linear trace may be detectable on aerial photo). Distance to lineament is the measured spatial parameter.

Group 2: Wells near to a lineament where a valley(coincide with paddy cultivation) is developed. This is detectable by contrast difference due land cover hence digital processing is also applicable using land satellite images. Distance to valley is the measured spatial parameter.

Group 3: Wells located near to the village tank(small to medium scale ancient reservoirs). Distance to tank is the measured spatial parameter.

Group 4: The wells which cannot be classified under the above group 1 and 2 have been considered under this group and classified as **interflues**(where hardly any detectable linear feature exists). Distance to the drainage divide is the measured spatial parameter.

In addition to above major groups, yield capacities of wells have been studied according to different different rock types such as Charnockites, Granites, Granitic gneiss and Hornblende biotite gneiss etc. Figures 3 and 4 show the yield capacities of tube wells related to the distance parameters in group 1 and 2.

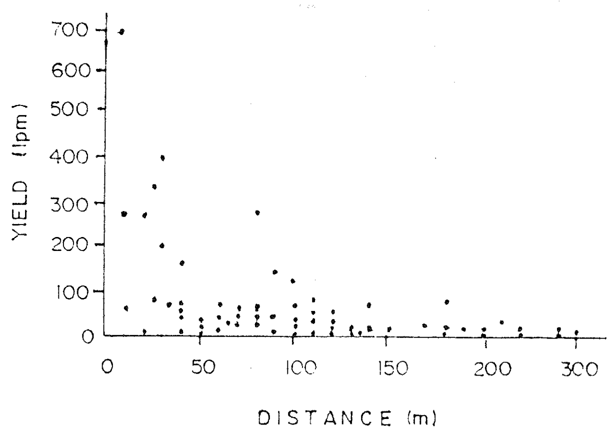


Figure 3: Scatter diagram, distance to valley

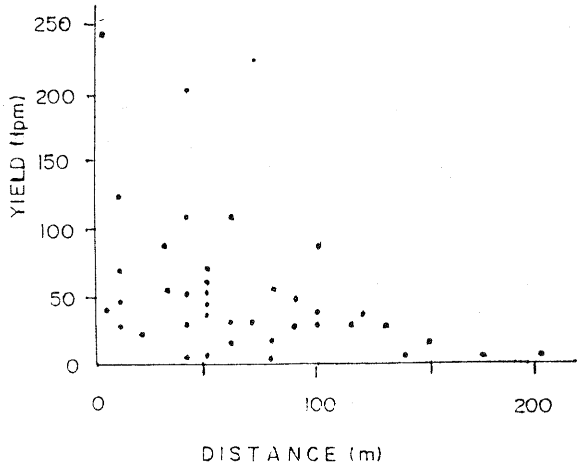


Figure 4: Scatter diagram, distance to lineament

Further analysis of well yields with respect to different directions of lineament and valley groups were carried out in order to establish decision rules for well location studies. Table1 shows the decision rules obtained from the analysis, mentioned above, which will be useful for groundwater exploration strategies with emphasis on well location on localized requirements.

Spatial feature	**Spatial feature**	**Decision rules (for well location)**
Lineament	Distance to lineament and lineament-direction	Favorable distance from the lineament = 0 - 90m Favourable direction = 60^0-120^0 and 120^0-150^0
Valley	Distance to valley and Valley direction	Favorable distance = 0 - 100m Favorable direction = 30^0W-30^0E
Tank	Distance to upstream and downstream of the tank	Distance to upstream = 0 - 150m Distance to downstream = 0 - 800m
Interflues	Distance to drainage divide	distance to drainage divide >200m
Drainage	Sream order	3^{rd} and 4^{rd} order are more favorable

Table 1.

MODELLING AND ZONING GROUNDWATER POTENTIALITIES

The main objective is to mapping favorable areas for groundwater occurrence on a regional scale. The model technique is adopted from AGTERBERG et.al(1988) who developed it for mineral explorations. The methodology can be used to estimate how much the prior probability that high yielding wells are present within a neighborhood is increased because of new evidence of factors which are favourable to it's occurrence. In this context, some spatial features used to establish decision rules have been considered as influencing factors on well yield. This can be explained as in figure 5 where a lineament was taken in to account as a influencing factor.

The **priori probability** (unconditional probability) of high yielding wells within a small arbitrary area can be calculated by area of occurrences of high yielding wells divided by the total area (**D/T**). Figure 6 is the venn diagram showing the association between an arbitrary of a lineament and are of high yielding wells.

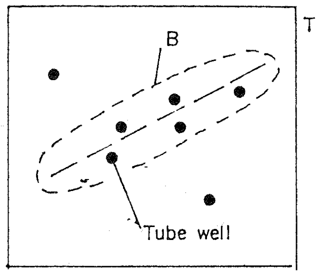


Figure 5

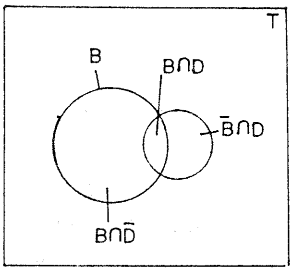


Figure 6

T - Study area

B - Area of map pattern
(lineament corridor)

D - Area of wells

Two weights can be defined for each map pattern for a quantitative estimation of the association between the binary map pattern and well location, as follows:

W^{+} = for those areas on the binary map pattern

W^{-} = for those areas off the binary map pattern

The above two weights have been calculated as log ratios of conditional probabilities using following equations:

$$W^{+} = \ln \frac{P(B/D)}{P(B/\bar{D})} = \ln \frac{(B \cap D)/D}{(B \cap \bar{D})/\bar{D}}$$

$$W^{-} = \ln \frac{P(\bar{B}/D)}{P(\bar{B}/\bar{D})} = \ln \frac{(B \cap D)/D}{(\bar{B} \cap \bar{D})/\bar{D}}$$

The measure of association between a map pattern and tube well points is given by W^{+} - W^{-} and denoted by C. Considering a lineament, as a spatial feature, the dialation operation available in the used geographic information system have been carried out create "buffer zones" to optimize the spatial association between lineament and well point. This was done by making a series of buffer zones around the lineament in order to create a distance map. This distance map, as a predictor map, would be very useful in determining optimum value for C, the reliable association, in order to include required weights for the model. For example for different dialated areas, it possible to calculate different C values as a function of distance to lineament. These predictor maps could be calculated for all spatial features which have been included in the model. Distances related each predictor map were within the range of the influencing distance for each map pattern as described in table 1. For a dialated lineament with 5 distance classes, the association has been calculated and obtained values for C are given in table 2. The weights and contrast ,C, for the other spatial features such as distance to valley, distance to tank, et. have also been calculated. For geological units, only positive weights were calculated as these units are mutually exclusive and the Table 3 shows calculated weights for different rock types.

Distance to lineament (m)	W^+	W^-	C
50	2.336	0.490	2.826
100	1.743	0.550	2.293
150	1.383	0.510	1.893
200	1.085	0.463	1.548
250	0.986	0.534	1.520

Table 2: Weights for lineament

Rock type	W^+
Charnockite	-0.319
Granite or Granitic gneiss	0.319
Hornblende biotite gneiss	-0.034

Table 3: Weights for rock types

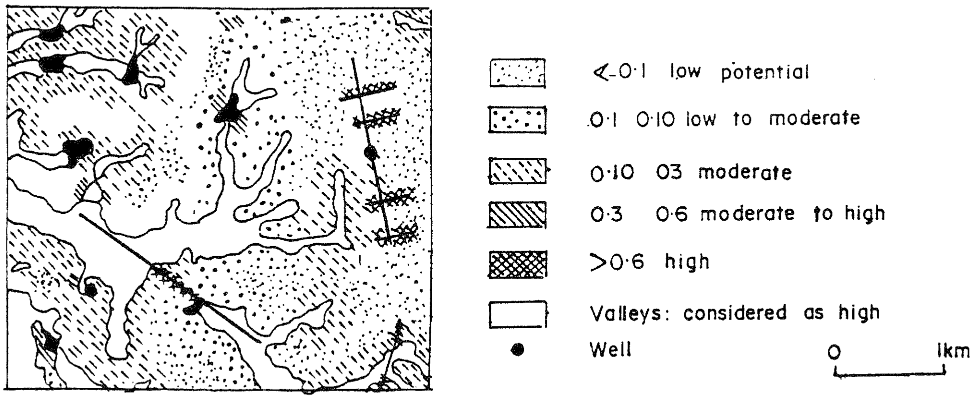
After obtaining the weights and contrast, C, for each predictor maps, the following equation has been used to integrate binary predictor maps in order to optimize the probability of obtaining high yielding wells.

$$O_{post} = \exp\left\{\ln(O_{prior}) + \sum_{j=1}^{m} W_j^k\right\}$$

Where, **O** odds, either prior or posterior, and is related to the probability **P** by O = P/(1-P).

$$W_j^k = \begin{Bmatrix} W^+ \text{for map pattern j present} \\ W^- \text{for map pattern j absent} \end{Bmatrix}$$

Finally a map of posterior probability indicating potential groundwater zones is created by calculating the posterior probability P_{post} as seen in figure 7.



Fgure 7: Posterior probability of groundwater occurences

CONCLUSIONS

Due to insufficient surface water resources, quick identification of potential groundwater zones play a main roll in implementing accelerated agricultural and industrial projects for which water supply is the major constraint. Therefore the detailed regional hydrogeological mapping together with surface geophysical surveys such as geo-electrical surveys cannot full fill this requirement as those geoscientific works should be carried out on long term exploration project basis. Also the cost and manpower required for these kind of exploration programs may not be sufficient to cover within the project budget specially in developing countries. To overcome this problems, the model described in this paper would give satisfactory support in as it facilitates quick identification of potential groundwater zones on regional basis with less labour-cost involvement. However, for the final site selection for drilling tube wells should be carried out by localized geophysical surveys such as geo-electrical profiling and soundings within the high potential ground water zones selected by the model, described above. Remote Sensing techniques such as interpretation of aerial photos and landsat imageries together with digital image processing is very useful in detection and extraction of relevant spatial parameters and GIS is useful in handling spatial data more efficiently.

ACKNOWLEDGMENTS

The author wish to acknowledge the technical support and advice given by Prof. Dr. A.M.J. Meijerink, Mr. B.C. Hansmans and Drs. D. Kovacs from the International Institute for Aerospace surveys and Earth Sciences (ITC), The Netherlands during this study period.

REFERENCES

1. Agterberg, F.P, G.F. Bonham-Carter and D.F. Wright 1988. Statistical pattern integration for mineral explorations. Proc: Cogeodata Symp. on computer application in resource exploration, Espo, Finland.

2. Bonham-Carter, G.F., F.P. Agterberg and D.F. Wright 1989. Weights of evidence modelling: A new approach to mapping mineral potential. Statistical applications in the earth sciences, Geological Survey of Canada, Paper 89 - 9, Ottawa.