AUTOMATED DECISION SUPPORT SYSTEM TO IDENTIFY AND APPLY GROUND WATER RECHARGE SOLUTIONS

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ABSTRACT

India is a developing country, but development in some areas is leading to chaos in others. The most witnessed example is the growth of infrastructure in India. Day by day huge buildings, offices, and localities are being constructed to meet the growing human requirements. Trees are being cut frequently giving rise to global warming and many other natural problems. The most threatening problem is the scarcity of water.

"Water has become a highly precious resource. There are some places where a barrel of water costs more than a barrel of oil."

Water resources of Earth can be classified as surface water and ground water in which groundwater is the main source for the domestic purpose and agriculture. We are utilizing the water inefficiently without providing sufficient ways to recharge it. In-fact the concrete structures like roads, buildings constraints the water to seep into ground properly. Whatever water is collected by rain is being drained off in rivers and water bodies outside the region. As a result there is shortage in drinking water. To save the world from this critical problem, we have to understand and find a solution to regain the ground water level.

Our paper defines an Automated Decision Support System and algorithm to identify and apply Ground Water Recharge Solutions using Geographical Information Science (GIS). This system identifies the error prone areas where water level is below threshold value or where it has reached a critical point. On these suspected points/areas, by applying the core rules for the installation of Recharge Structures, our system computes and suggests the optimal ARTIFICIAL RECHARGE TECHNIQUES. We have taken Ancillary Data, Satellite Data and other Decision Support data for suspecting the error prone areas. We are using SVM (Support Vector Machine) for supervised classification of the Satellite data.

Keywords: ground water, artificial recharge, GIS, SVM, integrated database values (IDV), ancillary data, satellite data

INTRODUCTION

In India, the dependence on ground water as a reliable source for meeting the requirements for irrigation, drinking and industrial uses has been rising rapidly during the last few decades. Ground water development has occupied an important place in Indian economy because of its role in stabilizing agriculture and as a means for drought management. Over the years, particularly since the launching of Five Year Plans, there have been continued efforts in India for development of ground water resources to meet the increasing demands of water supply for various sectors. In many parts of the country, ground water development has already reached a critical stage, resulting in acute scarcity of the resources.

Artificial Groundwater recharge is an efficient method of modifying the hydrological cycle and thereby providing abundant groundwater for usage. A unified approach of Satellite remote sensing and Geographical Information System (GIS) has opened new vistas for groundwater studies. This is due to the fact that earth observing devices; provide most up-to-date, accurate, unbiased and detailed spectral, spatial and temporal information on different conditions of natural resources. This paper addresses the strategies for an integrated approach of remote sensing and GIS used to provide a decision support system that ensures optimum and judicious use of groundwater by identifying and suggesting appropriate artificial recharge technique for the critical areas.

SYSTEM FLOW & METHODOLOGY

The system flow and methodology followed in our paper is based on input data which facilitates geo engine processing, and provides optimal recharge solution as output. The various types of input data required for processing are: user defined, Ancillary, Satellite & Decision support. Thematic Map is generated by applying sound decision rules and principles on Ancillary data and Satellite data. Other field observation data like ground water potential (Sub-Surface water potential) collected from specific departments combined with Thematic Maps results in the design IDV (INTEGRATED DATABASE VALUES) which is the standard for processing and analyzing ground water solutions based on various decision making factors.

Ancillary data

Ancillary data is used for the study of slopes, aspects, drainage network and other parameters that describes hydrogeology. Ancillary data is the integration of different types of maps required for computation and analysis.
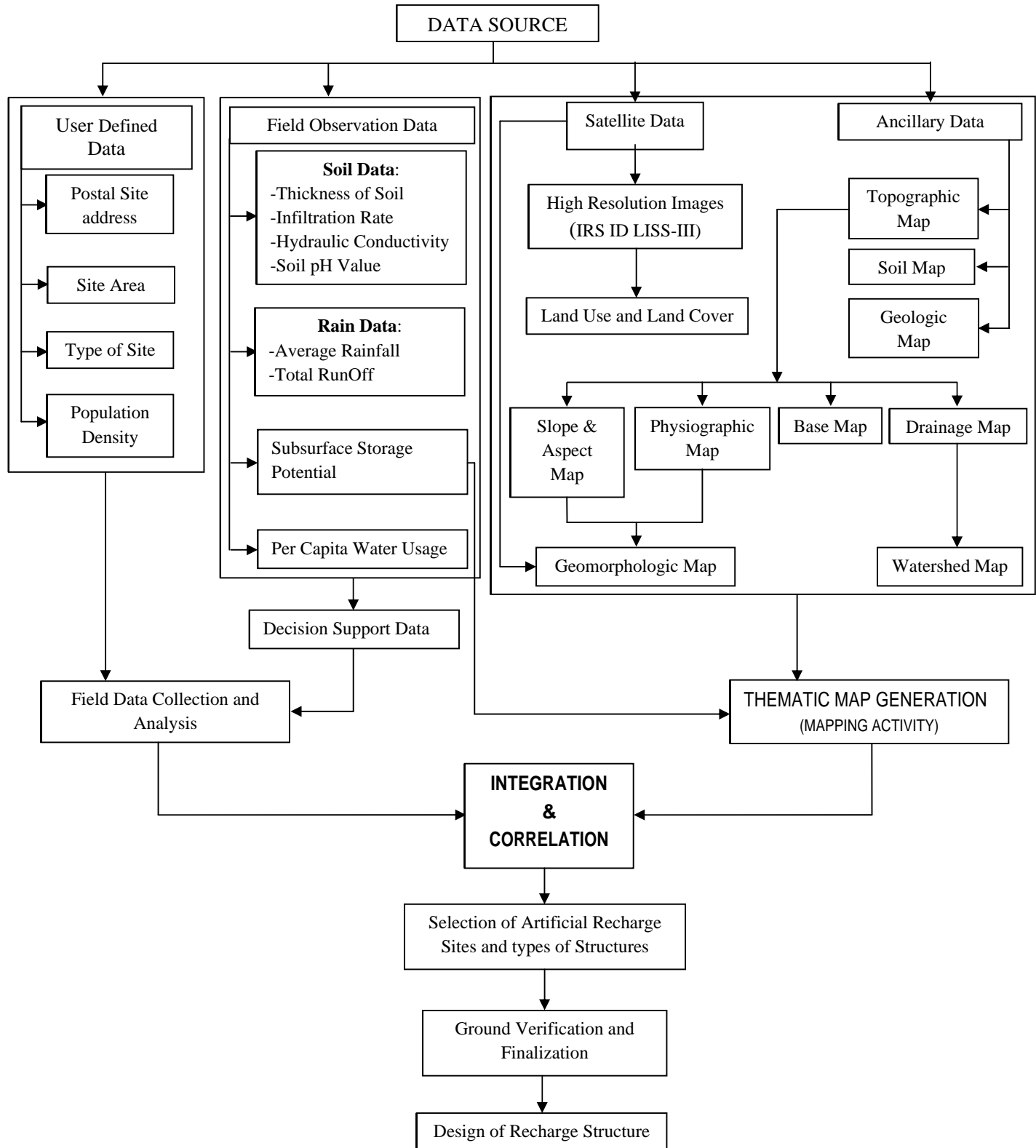
These maps are briefly explained below:

I.   **Topographic map:** Topographic map also known as contour maps, is 2-D representation of the earth's surface, showing shape, size and relative position of natural and manmade features at a very reduced scale.

II. **Soil map:** Soil map shows distribution of soil types and/or soil properties (soil pH, textures, organic matter, depths of horizons etc.) in the area of analysis.

III.   **Geologic map:** Geologic map shows the distribution of geologic features, including different kinds of rocks and faults. A geologic map is usually printed on top of a regular map (called a base map) to help you locate yourself on the map.

IV.   **Base Map:** Base map depicts visible surface features and boundary information about the Earth's surface, essential for locating additional layers or types of georeferenced objects. Base map may include features such as roads, rivers, major structures (buildings), contours, etc. In our paper, Base map provides the background on which thematic data is overlayed and analyzed.

V.   **Drainage Map:** Drainage map allow determination of drainage density, intensity, origin and degree of connectivity along with the extent of drainage networks associated with a region. The data from the map can be used, together with hydrological modelling, to predict a range of outcomes and to develop strategies for studying the drainage behaviour.

VI.   **Watershed map:** The watershed is a basic spatial reference unit in hydrology which helps to find out an area that topographically appears to contribute all the water that passes through a given cross section of a stream.

VII.   **Slope Map:** Slope is the rise or fall of the land surface and slope map gives information about degree (steepness) of slope for a particular terrain (or other continuous surface).

VIII.   **Aspect Map:** An aspect map shows to which side a slope is directed. Here it is used for estimation of rain (or, in some cases, chemical spills or leaks) run-off and direction.

IX.   **Physiographic Map:** This map characterizes diversity of different Earth's landforms i.e. terrain texture, rock type, geologic structure and history of that geographical region.   It   describes   the detailed mapping and description of particular localities, cities, and towns.

X.   **Geomorphologic Map:** Geomorphology is the scientific study of landforms and the processes that shape them. The objectives of geomorphologic map in our project is to understand the shape and structure of landscapes.

XI.   **Thematic map**: Thematic map focuses on a specific theme or subject area. Thematic maps use the base data and spatial variation of a number of geographical distributions. In this paper these distributions consist of slope, aspect, drainage, soil and rainfall which have been studied and used to generate Thematic Ground Water Map.

XII.   **Satellite Data**
There are many connections between land surface characteristic and water cycle. These land surface characteristics are constituted using Land cover and Land use data. Remote Sensing Satellite captures and provides high resolution images (Pan Sharpened Imagery, Stereo Pan Imagery) i.e. used successfully to classify the different land use/land covers.

DATA SOURCE

User Defined Data
- Postal Site address
- Site Area
- Type of Site
- Population Density

Field Observation Data

Soil Data:
-Thickness of Soil
-Infiltration Rate
-Hydraulic Conductivity
-Soil pH Value

Rain Data:
-Average Rainfall
-Total RunOff

Subsurface Storage Potential

Per Capita Water Usage

Satellite Data

High Resolution Images (IRS ID LISS-III)

Land Use and Land Cover

Ancillary Data

Topographic Map

Soil Map

Geologic Map

Slope & Aspect Map

Physiographic Map

Base Map

Drainage Map

Geomorphologic Map

Watershed Map

Decision Support Data

Field Data Collection and Analysis

THEMATIC MAP GENERATION (MAPPING ACTIVITY)

INTEGRATION & CORRELATION

Selection of Artificial Recharge Sites and types of Structures

Ground Verification and Finalization

Design of Recharge Structure

Fig. 1: Input data & System Flow Diagram

GEO ENGINE DECISION MAKING CRITERIA

Decision making criteria: -
- Source water and availability
- Available water storage capacity
- Clogging potential
- Rainfall pattern
- Land use and vegetation
- Cost

Based on these other important decision making criteria following is the table of artificial ground water recharge techniques:

Method Name	Type of Method	Slope	Soil and Rock Types	Topology
Flooding	Surface Spreading	Moderate to Gentle, Gentle	Clays, silts, sands and Gravels.	Land adjoining river/ irrigational canals.
Ditch and Furrows	Surface Spreading	Moderate , Moderate to Gentle	Clays, silts, sands and Gravels.	Irregular topography adjoining streams/canals.
Recharge Basins	Surface Spreading	Moderate , Moderate to Gentle, Gentle	Sandstones, Shales Clays, silts, sands andgravels.	parallel to ephemeral, intermittent stream-channels
Bench Terracing	Surface Spreading	Steep, Moderate	Granites, Limestones, Quartzites, Marbles, Basalts, Sandstones, Shales	Cultivated Land.
Contour Bunds and Contour Trenches	Surface Spreading	Steep, Moderate , Moderate to Gentle	Granites, Limestones, Quartzites, Marbles, Basalts, Sandstones, Shales	sloping gricultural lands with long slope lengths
Gully Plugs	Surface Spreading	Steep	Granites, Limestones, Quartzites, Marbles, Basalts, Sandstones, Shales	Small gullies, 1st order streams.
Nalah Bunds, Check Dams	Surface Spreading	Moderate , Moderate to Gentle	Granites, Limestones, Quartzites, Marbles, Basalts, Sandstones, Shales	1st-2nd order streams.
Percolation Ponds	Surface Spreading	Moderate , Moderate to Gentle	Granites, Limestones, Quartzites, Marbles, Basalts, Sandstones, Shales	Large reservoir areas and 2nd - 3rd order stream.
Injection Wells (Recharge Wells)	Sub-surface	Moderate, Moderate to Gentle, Gentle	Clays, silts, sands and gravels.	Areas where source of water is available either for some time or perennially e.g. base flow, springs.
Recharge Pits and Shafts	Sub-surface	Moderate to Gentle, Gentle	Granites, Limestones, Quartzites, Marbles, Basalts, Sandstones, Shales, Clays, silts, sands and gravels.	poorly permeable strata overlie water table aquifer located deep below land surface
Gravity Head Recharge Wells	Sub-surface	Moderate, Moderate to Gentle,	Granites, Limestones, Quartzites, Marbles, Basalts,	over-developed area have over-exploitation of

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		Gentle	Sandstones, Shales	ground water
Induced Recharge	Indirect Methods	Moderate to Gentle, Gentle	Granites, Limestones, Quartzites, Marbles, Basalts, Sandstones, Shales, Clays, silts, sands and gravels.	Aquifer hydraulically connected with surface-water source.
Bore Blasting	Indirect Methods	Moderate	Granites, Limestones, Quartzites, Marbles, Basalts	hard crystalline and consolidated strata

Table 1: Recharge Techniques and factors

ALGORITHM

Our automated decision support algorithm starts with computing spatial reference of user location Latitude (Lat), Longitude (Long) by a well known Geocoding process. Now user site is extracted from satellite imagery by Support Vector Machine (SVM) that serves as key parameter for GETSCALE( ). This all important information is passed in DECISIONSUPPORTDATA( ) function discussed later to calculate all decision affecting parameters.
Main class of algorithm is as follows: -

begin

 (Lat, Long) = Geocoding (Postal Address);

(TypeofLand, LandStructure) = GETLANDUSE ((Lat,Long), LandUse, LandCover);

Scale = GETSCALE (TypeofLand);

ToposheetNumber = GETTOPOSHEETNUMBER ((Lat, Long), Scale);

DECISIONSUPPORTDATA ((Lat, Long), TypeofLand, LandStructure, ToposheetNumber);

ThematicGroundWaterMap = THEMATICMAPPINGFUN (Ancillary Data, Satellite Data, SubsurfaceStoragePotential);

IntegratedDatabaseValue = ThematicGroundWaterMap + Decision Support Data;

factorList = FETCHFACTOR (IntegratedDatabaseValues);

optimalSolution = COMPARISIONFUN (factorList, StandardFactorList);

artificialRechargeTechDeployedonMap = MAPPINGFUN(BaseMap,ThematicMap, optimalSolution);

end

The following order of sequence was adopted to derive the final integrated thematic ground water map.

Geology (I1) + Geomorphology (I2) + Soil (I3) = O1
O1 + Landuse/Landcover (I4) = O2
O2 + Drainage of 50 m buffer (I5) = O3

Geology (I1), Geomorphology (I2) and Soil (I3) layers were integrated by the union operation. Adding these three layers derives the weight of each polygon in the integrated layer (O1). In the next step, the (O1) layer is intersected with the land use layer (I3). In this step, the integrated layer (O2) was generated by adding lithology, geomorphology, soil and landuse layers. The (O2) layer is integrated with polygons made around the drainage (buffer zone) by the union operation. The polygons in the integrated layer (O3) when combined with the Subsurface Storage Potential of corresponding zone results a composite detailed thematic ground water Map.

Now thematic Ground water map and computed decision support data is integrated to generate IDV which in turn is queried according to factors affecting recharge structure and system generates best optimal recharge structure.

Site Selection from Satellite Imagery

To detect the candidate site patches, first, Digital Terrain Model (DTM) is generated from existing vector data. Then, Digital Surface Model (DSM) is generated from the high resolution stereo panchromatic image pairs. After generating DTM and DSM, a normalized Digital Surface Model (nDSM) is calculated by subtracting DTM from DSM and then 3D objects are separated by applying 3m threshold to nDSM. Next, an orthoimage is generated from high resolution satellite images using DSM. The orthorectification of the image is necessary to accurately overlay image with reference site database. Next, a Normalized Difference Vegetation Index (NDVI) is calculated. To detect the candidate site patches, orthorectified high resolution image with additional bands nDSM and NDVI is classified using SVM classifier.

Here SVM classification is performed. The Radial Basis Function (RBF), which can handle linearly non-separable problems; is selected as kernel method. The γ is determined as inverse of number of bands in the input image and 1000 is taken as value of C. The candidate site class is class of interest, while all other classes are composed as non-candidate site class.

After performing binary SVM classification, those areas classified as site represent the candidate site patches and all others are excluded. To obtain the site boundaries, the detected site patches in raster form are converted into vector form. To do that, initially the edges are detected using an edge detection algorithm. The resulting edge image is a binary image that shows the edges of the candidate site patches. These edges are then converted into vector form using a Hough transform, which is a widely used method for extracting the lines and/or curves forming the objects. After detecting the lines and/or curves in vector form, they are grouped perceptually to obtain the candidate -site boundaries.
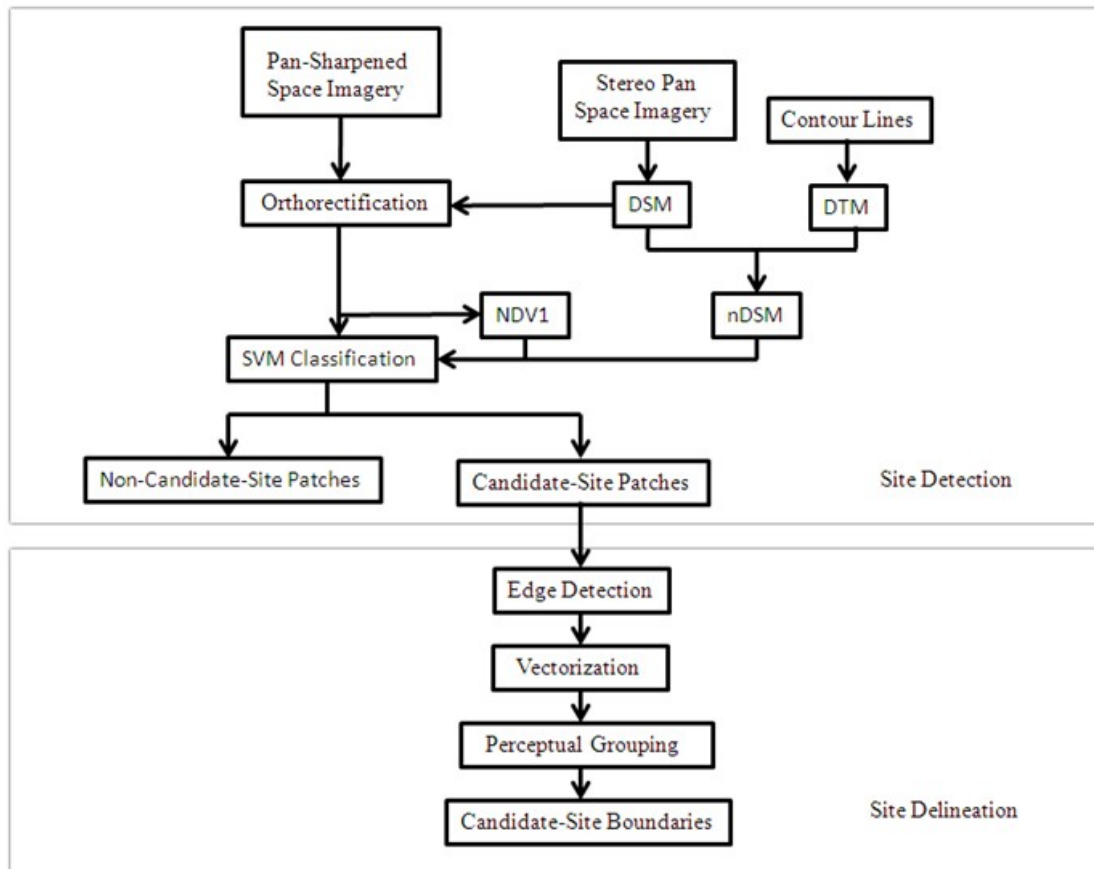

Fig. 2: Site Detection and Delineation Technique

Decision Support Algorithm

Thematic layers generated using remote sensing data like geology, geomorphology, land use/land cover, drainage etc. can be integrated in a Geographic Information System (GIS) framework and analyzed using a DECISIONSUPPORTDATA ((Lat,Long),TypeofLand, LandStructure, ToposheetNumber) function.

DECISIONSUPPORTDATA ((Lat,Long),TypeofLand, LandStracture, ToposheetNumber)
{

      AvgRainFall = GETAVGRAINFALLDATA (ToposheetNumber);

      RunOffCofficient = GETRUNOFFCOFFICIENT (LandStracture);

      TotalRunOff = RunOffCofficiet * AvgRainFall ;

      Acz = AREACALCULATION (ContourMap(avgWaterLevel), thresholdWaterLevel);

      Sm = AQUIFERMATERIALYIELD (SoilMap, physiographic map);

      TotalSubsurfaceStoragePotential = (Acz *Sm);

      SoilPermeability = GETPERMEABILITY ((Lat,Long), SoilMap, BaseMap);

      PerCapitaWaterUse = SuppliedWater/PopulationDensity;

/* Other Important *Empirical Decision support data: -*
- Source of Water except Rainfall
- Thickness of Soil
- Infiltration Rate
- Soil pH Value

*/
}
Where Acz = area of critical zone & Sm = aquifer material yield

Rainfall and Runoff

Availability of source water is one of the basic prerequisites for taking up any artificial recharge scheme. Rainfall and runoff available constitute the major sources of water for artificial recharge of ground water.

Length of rainfall data records to be considered is an important factor in the analysis of rainfall. In India Meteorological Department established many rain gauge stations across the country to measure average annual rainfall records. As per the defined algorithm we first collect these average rain fall records from rain gauge station in specified zone defined by following function.

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```
GETAVGRAINFALLDATA (ToposheetNumber)
{
RainGaugeStationsList = GETRAINGAUGESATIONLIST (ToposheetNumber);
Sum = 0;
        for Loop i = 1 to RainGaugeStationLsit.Size
        Start Loop
                RainFallData = getRainFallData (RainGaugeStatioList[i]);
                Sum = Sum + RainFallData ;
        End Loop
AvgRainFall = Sum/ RainGaugeStationList.Size;
return (AvgRainFall);
}
```

Runoff is defined as the portion of the precipitation that makes its way towards rivers or oceans as surface or subsurface flow. Precise estimation of runoff is the basic and foremost input requirement for the design of recharge structures of optimum capacity. Our algorithm using Coefficients method to estimate runoff where we first select runoff coefficient by GETRUNOFFCOFFICIENT (LandStructure), function for specified Land Structure then by simple multiplying runoff coefficient and average rain fall data we get Total Run off.

```
GETRUNOFFCOFFICIENT (LandStructure)
{       switch (LandStructure)
        {
Case Urban Residential:          RunOff = 0.3 - 0.5;   Break;
Case Forests:                    RunOff = 0.05 - 0.2;  Break;
Case Commercial & Industrial:    RunOff = 0.9;         Break;
Case Parks, farms, Pastures:     RunOff = 0.05 - 0.3;  Break;
Case Asphalt or concrete pavement: RunOff = 0.85;      Break;
        }
return (RunOff);
}
```

The scope for artificial recharge in an area is basically governed by Sub-surface Storage Capacity of that Aquifer. Depth to water level, therefore, provides the reference level to calculate the volume of unsaturated material available for recharge. The average water levels for a period of at least 5 years is to be used in order to nullify the effects of variation in rainfall. AREACALCULATION function is used to identify the critical area (Acz). Function uses Contour maps prepared from the average post-monsoon water level data with suitable contour intervals used for assessment of available storage space. The intercontour areas

between successive contours are determined and the total area in which the water levels are below a certain cut-off level (3.00 m.bgl in phreatic aquifers), multiplied by the specific yield of the aquifer material (Sm) gives the volume of subsurface storage space available for recharge.

Acz = AREACALCULATION (ContourMap(avgWaterLevel), thresholdWaterLevel);
Sm = AQUIFERMATERIALYIELD (SoilMap, physiographic map);
TotalSubsurfaceStoragePotential = (Acz *Sm);

CONCLUSIONS

This technology can be used by Municipal Corporation for Advance Town Planning in which it will suggest which areas are suitable for new constructions or what optimal technique should be implemented on the existing infrastructure for groundwater recharge. It can also be used for providing Agro-based solutions.

It may not always be possible to implement artificial recharge projects in all conditions, due to various constraints such as lack of source water, shortage of funds for implementation of the projects etc. In such cases, it may be necessary to identify areas that require recharge augmentation most and to implement recharge projects accordingly.

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I am Anuj Tiwari presently pursuing M.Tech in Spatial Information Technology from DAVV, Indore. I am hired as an intern for one year at Centre for Artificial Intelligence and Robotics, DRDO Bangalore under the same programme. Here I am currently working on Web based GIS Technology apart from this my technical interests are in the area of Computer Networking, Distributed and parallel Computing. And one of my papers is accepted in International Conference on Computer and Communication (ICCC) which will be held in January 2012.I got my graduation degree from Rajiv Gandhi Proudyogiki Vishwavidyalaya with an aggregate of 76.7 % . Here I got an opportunity to do my major project on embedded systems technology. Apart from this I also implemented the solution to Tower of Hanoi problem and presented it as a GUI as a part of my minor project.

I am Akshit Mahajan, presently pursuing BE in Computer Science and Engineering from Chitkara University Baddi, Himchal Pradesh. I recently finished my 6-months project training at Centre for Artificial Intelligence and Robotics, DRDO Bangalore in the Geographic Information System group where I worked on Bathymetric Surface generation and analysis. My areas of technical interest are image processing and visualization.