AHP TECHNIQUE USE FOR DEVELOP GIS MODEL OF GROUNDWATER POTENTIAL ZONE IN PARTS OF BHOPAL DISTRICT

Amit Daiman*

Narendra Gupta**

Abstract

Water is the most important natural resource that supports life of planetary Earth. It is the basic need of human to carry out their routine activities. In this case study, an attempt has been done to delineate groundwater potential zones in Kaliyasote Milli-Watershed in Bhopal district, Madhya Pradesh, India covering an area of 84 sq. km. The various thematic maps namely geological, geomorphological, lineament, slope, drainage and drainage density have been generated using IRS (P6-resourcesat) LISS III data and referenced by Survey of India (SOI) toposheets. The information extracted from all the thematic maps have been integrated in GIS environment and all process have been done in the geoprocessing modular builder tool in ArcGIS. ModelBuilder engine is a comprehensive geographic decision support tool that makes the solving of complicated problem simple. each map has given some weightage based on its suitability to groundwater. The method adopted to assign weightage has Analytic Hierarchy Process (AHP) which produced considerable results. On the basis of hydrology and geomorphic characteristics, six categories on groundwater prospect zones have been identified i.e. excellent, very good, good, moderate, poor and very poor to NIL. The analysis reveals that the lineaments on pediplain have excellent groundwater potential followed by pediplain with very good to good potential whereas plateau remnants, lateritic uplands and cuesta have moderate to very poor potential.

Keywords: ArcGIS Model, Groundwater prospect, Analytic Hierarchy Process, Remote Sensing & GIS.

* GIS Assistant MP Council of Science & Technology, Bhopal

** Lecturer Dept. of Geography, Govt. College Chhitourgarh

1. Introduction

Rapid industrial development, urbanization and increase in agricultural production have led to freshwater shortages in many parts of the world. Almost every species depends on water for its survival. The increasing population is generating a huge demand of fresh and potable water supply but the available surface water is inadequate to fulfill this requirement, as a result more stress has been experienced to the groundwater resources which is the largest as well as the most economical source of fresh water supply as it undergoes lower levels of contamination and wider distribution whereas surface water needs to be treated before supply. The shortage of water is a major concern for all living beings. About 70% of the global surface is covered with water in the form of oceans, seas, rivers and lakes. The 97.3% of the water available on the Earth is saline and the remaining 2.7% is available as fresh water, out of which 79% lies in Polar Regions or in deep aquifers, 20% groundwater and rest 1% in lakes. The occurrence of groundwater is not a matter of chance but a consequence of the interaction of the climatic, geological, hydrological, physiographical and ecological processes of nature. The exploration operation is essentially a hydrogeological and geophysical influence-operation and depends on the correct interpretation of hydrological indicators. The movement of groundwater is mainly controlled by porosity and permeability of the rocks. The lithology forming different geomorphic units will have variable porosity and permeability and thereby causing changes in groundwater potential. The surface water bodies like tanks, ponds, river, stream, lakes, springs etc. act as the recharge zones for groundwater. The Remote Sensing techniques are playing an important role in identifying the groundwater potential zones. These techniques have been proven as an excellent tool for understanding the perplexing problems related to groundwater exploration and have been well recognized in geological society. The remote sensing satellite images, in conjunction with District Resource Maps (DRMs) provides better understanding for a particular area and thus, helps in analyzing the various aspects like geomorphology, geology, structural, hydrogeology etc. The information retrieved from Remote Sensing techniques in integrated in the Geographical Information System (GIS) which comprises of software's that helps in further analysis of data and thus helps in generating Digital Elevation Models (DEMs), inventory, groundwater potential maps and various types of modeling.

2. Study Area

The study area is a milli-watershed of the Kaliyasote River located at South-East region of Bhopal district which is the capital of Madhya Pradesh, India lying between North latitudes $23^{0}13'42''$ – $23^{0}6'10''$ and East longitudes $77^{0}21'11''$– $77^{0}30'27''$ falling in Survey of India toposheet no. 55E/8 and 55E/12 in parts, covering an area of about 84 sq. kms (figure 1). Bhopal district headquarter is situated at about 10 kms from the study area.

3. Data Used

Indian Remote Sensing (IRS-P6 Resourcesat) satellite Linear Imaging Self Scanning (LISS) - III (spatial resolution 23.5m) data pertaining to path no. 97 and row no. 56 dated 13th November 2005 and 24th January 2006 have been used. For a generation of DEM and slope map SRTM data has been used. Survey of India (SOI) toposheet nos. 55E/8 and 55E/12 (1:50,000 scale) have been used for information related to settlements, roads, drainage, water bodies etc. The District Resource Map (DRM) of the Geological Survey of India pertaining to the Bhopal district has also consulted for information related to geology, geomorphology and structural elements.

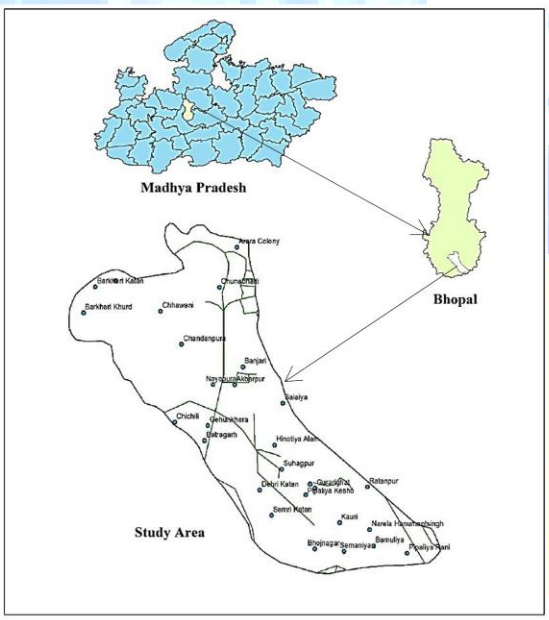


Figure 1: Study Area

4. Methodology

The methodology used for the generation of groundwater prospect map is shown in figure 2. The satellite data and ancillary data were used for the generation of various thematic layers namely lineaments, slope, base, drainage, drainage density, geology and geomorphology. Integration of all the layers under GIS environment resulted in final groundwater prospect map.

5. Thematic Layers

The satellite data that have been used had undergone image preprocessing in order to correct distortions and to create more faithful representation. The image was georectified with geographical coordinate system WGS 1984 and projected coordinate system Lambert Conformal Conic projection. After preprocessing work, the image enhancement was done to improve the visual impact and to make the image more interpretable. The other actions that were performed were mosaicking to combine the satellite images and sub-setting to crop the study area from the satellite image.

5.1.Interpretation of Satellite Data

The False Color Composite (FCC) satellite image of the study area can be seen in figure 3. The red tone in image represents vegetation which is basically Rabi crops as the image has taken in January. The two water bodies can be seen in the north, as their tone is dark which indicates deep water bodies. Light blue tone with rough texture represents settlements in the area and in between some straight lines can be seen which are roads. The various geomorphic units having some relief can be seen in the northern flank of the study are with greenish blue tone and smooth to slight rough texture. The linear feature adjoining to a waterbody is Kaliyasote dam and the irregular linear feature is Kaliyasote River flowing downstream and drainage lines.

5.2.Drainage Network

The Drainage lines in the area were derived by digitizing topographic map overlaying by satellite image (figure 4) so that the existing and non-existing streams can be detected precisely. The drainage patterns that were observed in the study area were dendritic, sub-dendritic and sub-parallel.

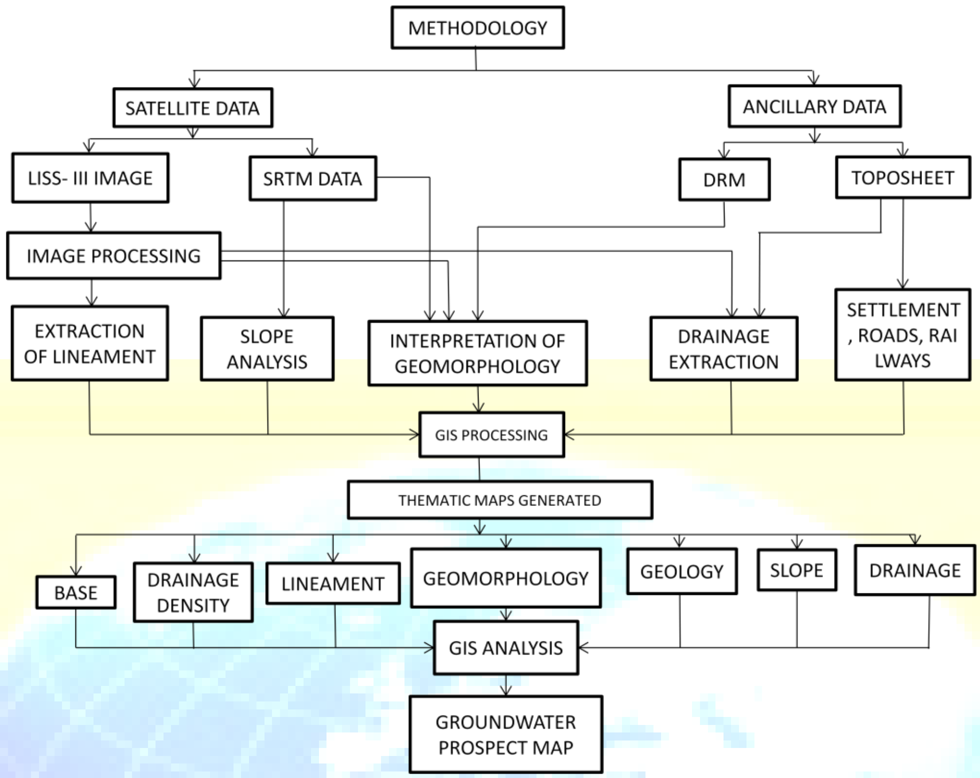
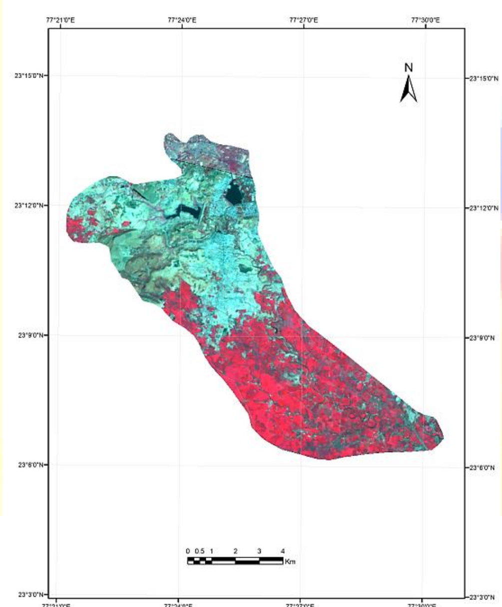


Figure 2: Methodology



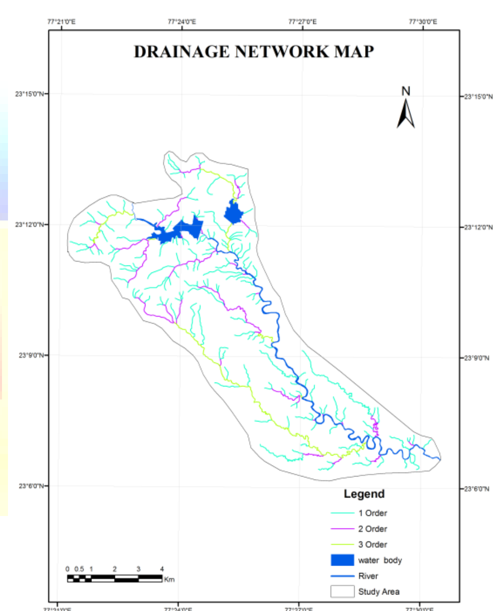


Figure 3: Satellite Image Figure 4: Drainage Network

5.3.Drainage Density

The drainage density layer was created by using spatial analyst tool in ArcMap toolbox (figure 4). Higher the stream order lower will be the drainage density and more will be the infiltration and vice versa. Since majority of the area is under low drainage density indicating good infiltration and less runoff of water.

5.4. Digital Elevation Model (DEM)

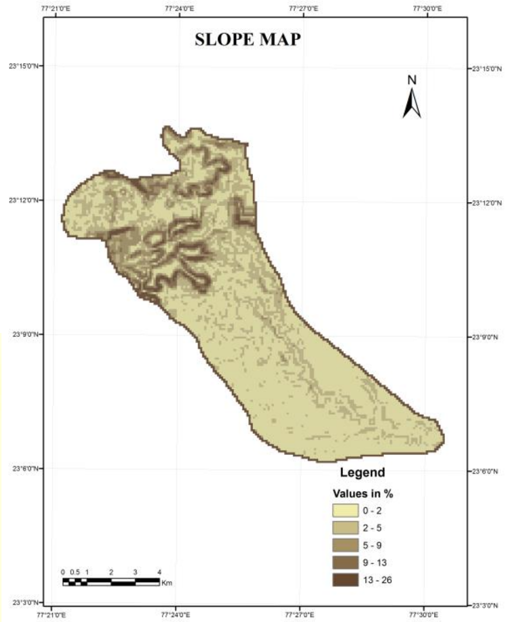
The Digital Elevation Model was derived from SRTM and it was imported in ArcMap for generation and analysis of slope.

5.5. Geology/Lithology

Geologically, the district is occupied by the rocks of Vindhyan Super Group, Deccan Trap, Laterite and Alluvium. The Vindhyan Super Group (900-1400ma) mainly includes sedimentary formations of which the oldest Rewa sandstone is locally designated as Nawarganj sandstone. The rocks of Vindhyan Super Group host well developed sedimentary structures namely bedding, cross bedding, ripple marks etc. Basaltic lava flows of the Deccan Trap ranging in age from Upper Cretaceous to Lower Palaeocene occupy the vast area of the north, central and western parts of the district and have been classified into three formations viz Kalisindh, Kankariya, Pirukheri. Weathering and accumulation of fragments of laterite andsubsequent consolidation has given rise to secondary laterite in the district.Alluvium occupies the river valleys and plains and has been classified as older and new alluvium. Older alluvium mainly comprises yellow, grey, reddish brown clays with gravel horizons whereas younger alluvium is confined to present day flood plains of the major rivers and streams and consist mainly of sand, silt and subordinate amount of clay in the district.

5.6. Geomorphology

The geomorphology of the study area comprises of cuesta in the northern corner which is a hill with gentle slope on one side and steeper slope on the other side. It is least favorable to groundwater. Lateritic uplands which are the formation of chemically weathered subsoil's rich in oxides of iron, bauxite or both, Plateau remnant which is a flat area of great extent and elevation above the sea level, Pediments which are gently sloping rock surface having moderate relief, Pediplain in the southern part of the study area which is a low leveled extensive spread of rock sediments and are most favorable to groundwater and meander scar which is a crescentic, concave markon the face of a bluff or valley wall, produced by the lateral plaination of a meandering stream which undercut the bluff, and indicating the abandoned root of the stream.



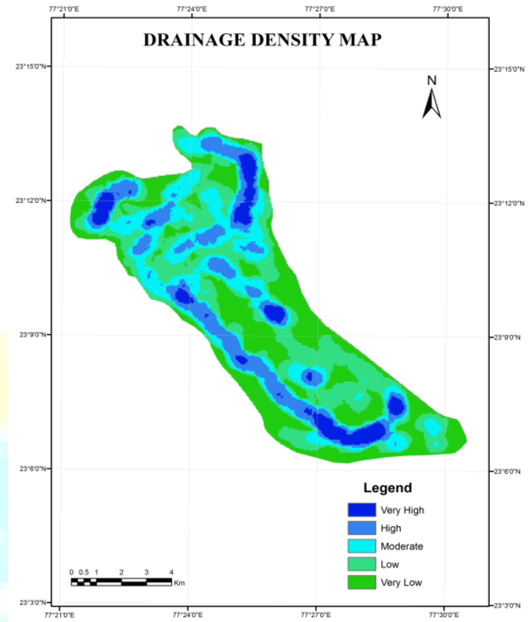
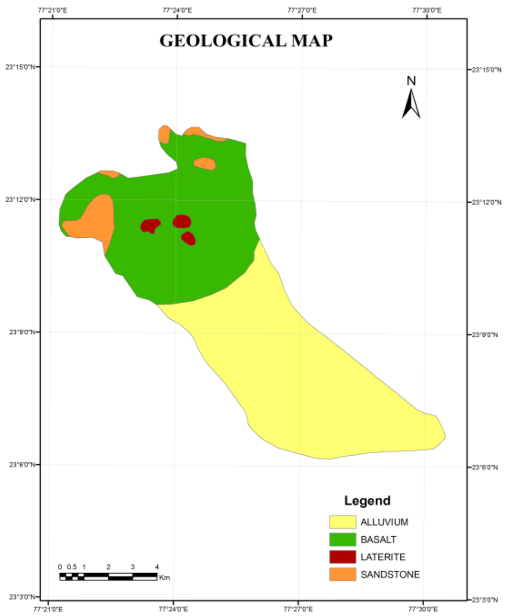


Figure 5: Slope Map   Figure 6: Drainage Density

5.7. Structures

The lineaments in the study area were extracted by visual image interpretation. The image has enhanced and under gone various band combinations (figure 9). They were easily identified by drainage streams due to their linear shape at some places. All the lineaments in the study area are micro- lineaments as their length are less than 3 km. The lineament density is more in the northern part of the study area; their general orientation is aligned along NWSE direction. The lineaments are the result of various faults and fractures they infer that they are the zones of increased porosity and permeability, which in turn has greater significance in groundwater potential and its distribution. Lineaments can be identified from remote sensing based on their linear nature, presence of moisture, alignment of vegetation, alignment of ponds, straight stream segments etc.



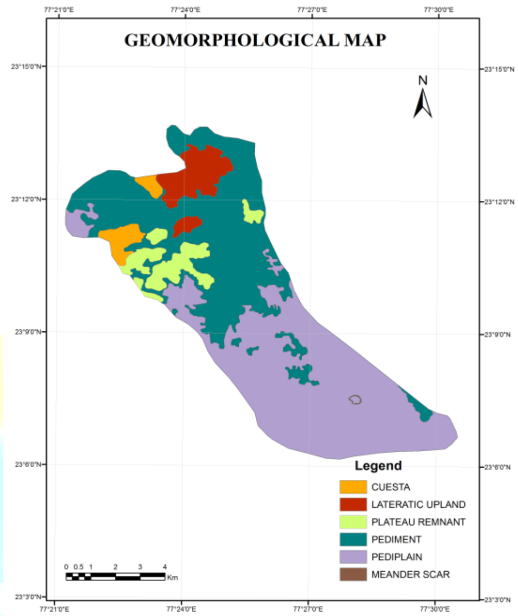


Figure 7: Geological/Lithology Map Figure 8: Geomorphological Map

6. Integrated GIS Analysis

The vector data layers derived have been finally converted into raster data sets having the same pixel size. Each data set in a single map was assigned weightage by pair wise comparison. The method adopted to assign weightage has Analytic Hierarchy Process (AHP) by Thomas L. Saaty (1977) which is the most widely used decision making approach in the world today. In this method, each class in a particular thematic map was assigned a rating by pair-wise comparison between classes based on their relative importance. The initial ratings were adopted from continuous rating scale developed by Saaty.

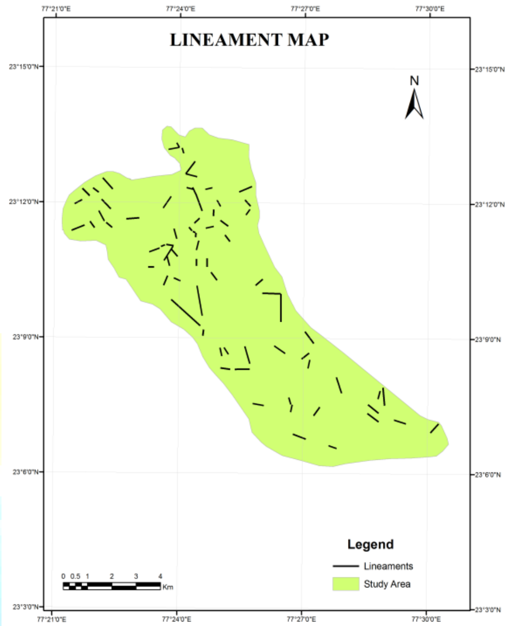


Figure 9: Structural Map

Table 1: Saaty's Continuous Rating Table

Extreme	1/9	Moderate	1/3	Strong	5
Very Strong	1/7	Equal	1	Very Strong	7
Strong	1/5	Moderate	3	Extreme	9

6.1.Weightage Assignment

The AHP method is based on the well-defined mathematical structure of consistent matrices and their associated right Eigen vector's ability to generate true or approximate weights. The weightage assignments of all the groundwater controlling factors are given below.

Table 2: Computing of Weights for Lineaments of the study area

Distance/s (mtr)	>150	100-150	50-100	0-50	Weight	Weight*100
>150	1	0.143	0.111	0.091	0.036	4
100-150	7	1.000	0.778	0.636	0.250	25
50-100	9	1.286	1.000	0.818	0.321	32
0-50	11	1.571	1.222	1.000	0.393	39

Table 3: Computing of Weights for Drainage lines of the study area.

Drainage Order	V.HIGH	HIGH	MODERATE	LOW	Weight	Weight*100

1 order	1	0.333	0.200	0.143	0.063	6
2 order	3	1.000	0.600	0.429	0.188	19
3 order	5	1.667	1.000	0.714	0.313	31
No order	7	2.333	1.400	1.000	0.438	44

Table 4: Computing of Weights for Drainage Density of the study area.

Drainage Density	V. HIGH	HIGH	MODERATE	LOW	V.LOW	Weight	Weight*100
V.HIGH	1	0.333	0.200	0.143	0.111	0.039	4
HIGH	3	1.000	0.600	0.429	0.333	0.116	12
MODERATE	5	1.667	1.000	0.714	0.556	0.193	19
LOW	7	2.333	1.400	1.000	0.778	0.270	27
V.LOW	9	3.000	3.000	1.286	1.000	0.384	38

Table 5: Computing of Weights for Slope of the study area.

Slope Type	VERY STEEP	STEEP	MODERATE	GENTLE	FLAT	Weight	Weight*100
VERY STEEP	1	0.334	0.2	0.143	0.112	0.057	6
STEEP	3	1	0.6	0.429	0.334	0.137	14
MODERATE	5	1.667	1	0.714	0.556	0.206	21
GENTLE	7	2.337	1.4	1	0.778	0.27	27
FLAT	9	3	1.8	1.285	1	0.33	33

Table 6: Computing of Weights for Geology of the study area.

Lithology	BASALT	LATERITE	SANDSTONE	ALLUVIUM	Weight	Weight*100
BASALT	1	0.333	0.200	0.111	0.056	6
LATERITE	3	1.000	0.600	0.333	0.167	17
SANDSTONE	5	1.667	1.000	0.556	0.278	28
ALLUVIUM	9	3.000	1.800	1.000	0.5	50

Table 7: Computing of Weights for Geomorphology of the study area.

Landforms	CUESTA	LATERATIC UPLAND	PLATEAU REMNANT	PEDIMENT	PEDIPALIN	MEANDER SCAR	Weight	Weight*100
CUESTA	1	0.333	0.200	0.143	0.111	0.091	0.028	3
LATERATIC UPLAND	3	1.000	0.600	0.429	0.333	0.273	0.084	8
PLATEAU REMNANT	5	1.667	1.000	0.714	0.556	0.455	0.139	14
PEDIMENT	7	2.333	1.400	1.000	0.778	0.636	0.194	19
PEDIPALIN	9	3.000	1.800	1.286	1.000	0.818	0.250	25
MEANDER SCAR	11	3.667	2.200	1.571	1.222	1.000	0.305	31

6.2.Overlay Analysis

The Overlay Analysis is the final step after reclassification of raster datasets. The overlay analysis was done in ArcGIS ModelBuilder engine by using Overlay tool from spatial analyst tool. The function of this tool is to integrate all the input raster dataset. Every reclassified raster dataset added in overlay table is given an influence factor. The influence factors have been given to all reclassified raster data sets is mentioned in Table 8.

Table 8: Computing of Weights for all thematic maps which will be the influence factors for overlay analysis

RECLASSIFIED MAPS	DRAINAGE NETWORK	GEOLOGY	DRAINAGE DENSITY	SLOPE	GEO-MORPHOLOGY	LINEAMENT	Influence	Influence*100
DRAINAGE NETWORK	1	0.333	0.200	0.143	0.111	0.091	0.027	3
GEOLOGY	3	1.000	0.600	0.429	0.333	0.273	0.084	8
DRAINAGE DENSITY	5	1.667	1.000	0.714	0.556	0.455	0.139	14
SLOPE	7	2.333	1.400	1.000	0.778	0.636	0.194	19
GEO-MORPHOLO	9	3.000	1.800	1.286	1.000	0.818	0.250	25

GY								
LINEAMENT	11	3.667	2.200	1.571	1.222	1.000	0.305	31

6.3.GIS Modeling

As mentioned earlier, Model Builder of ArcGIS 10 (Arc Toolbox) has been used in developing the groundwater potential model (Figure 10). The groundwater potentiality of the area has been assessed through integration of the relevant layers, which include Drainage Network, Geology, Drainage Density, Slope, Geomorphology and Lineament in the ArcGIS modular builder.

7. Results and Discussions

The area under study is mostly occupied by the alluvial rock formation susceptible for the occurrence of groundwater. Based on the GIS approach, the groundwater prospective zones have been identified; occupying central as well as southern part of the study area. Monitoring of the existing dug wells, and tube wells may also enable to arrive at a judicious explanation about the sustenance of available groundwater resource in the region. The intersecting nature of structural elements (lineaments) has been proven to be more accurate judgment for the occurrence of underground water resource in the region. The Analytic Hierarchy Process (AHP) has been proven to be an efficient method to delineate groundwater potential zones by providing suitable weightage. A deep study of AHP is required to generate more accurate results. The efficiency of the results of AHP is based on the initial ratings which are knowledge base. More accurate these ratings, more accurate will be the results; hence field investigation need to be done. The data related to static water level (seasonal), water level fluctuations, recuperation, geophysical investigations may better lead to achieve more precise estimation about the available groundwater resource in the region.

8. Conclusion

A model has been developed to assess the groundwater potential of a Karawan watershed area by integrating six hydrogeologic themes through GIS using AHP technique. The AHP has been proven to be an efficient method to delineate groundwater potential zones by providing suitable weightage. The accuracy of the results of AHP is based on initial ratings which are knowledge based and AHP technique is effective for identification of different groundwater potential zones in smaller areas.

The verification of this model undoubtedly establishes the efficacy of the GIS integration tool in demarcating the potential groundwater reserve in soft rock terrain. The most promising potential zone in the area is related to volcanic rock of which is affected, by secondary structure and having interconnected pore spaces, with plain geomorphic feature and less drainage density. Most of the zones with poor to very poor groundwater potential lie in the massive basement unit, which is far from lineaments. The intersecting nature of the lineaments has been proven to be a more accurate judgment for the occurrence of the groundwater resource.

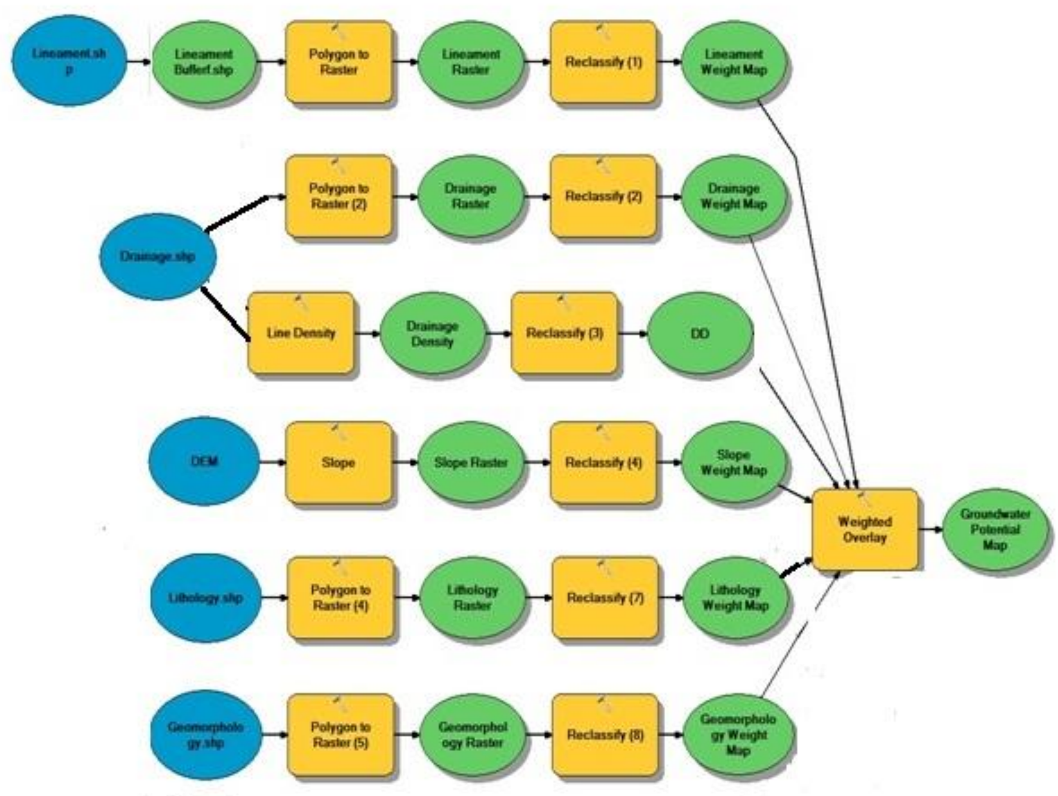


Fig 10; Groundwater Potential Model

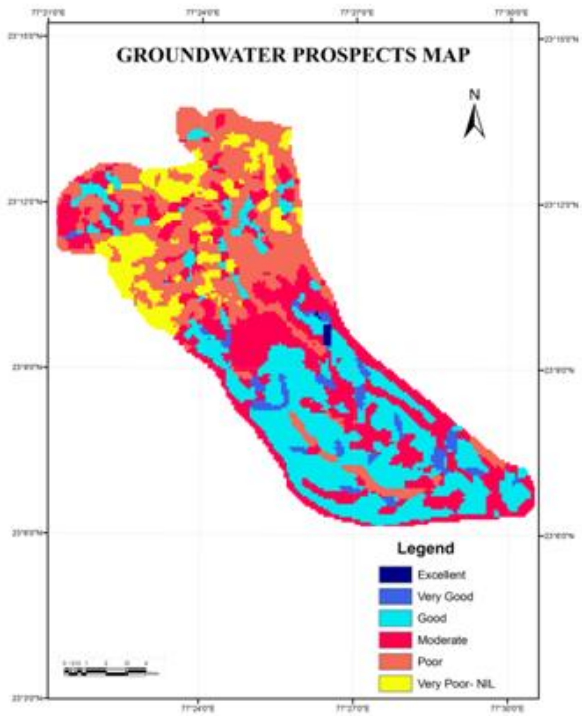


Figure 11: Groundwater Prospect Map

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