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APPLICATION OF A RS AND GIS BASED SEMI-QUANTITATIVE APPROACH TO ANALYZE GROUND WATER POTENTIALITY IN KANGSHABATI IRRIGATION COMMAND AREA WEST BENGAL

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ABSTRACT

In the present study, Remote Sensing technique and GIS tools based Analytical Hierarchy Process (AHP) is applied to prepare the Ground Water Potential Zones of Kangshabati Irrigation Command Area. In this process, all the extracted thematic maps are integrated by Weighted Linear Combination Model (WLCM) multiplying prioritized class rating value and factor rating values (principal eigenvectors) and using MATLAB Software. Finally, an accuracy assessment is made in ERDAS Imagine Software by ground truth verification of 21 training sites with GPS readings for major land use/ land cover information which states the overall classification accuracy of the present study is 70.37%.

Key Words: *RS and GIS, Analytical Hierarchy Process (AHP), Consistency Ratio (CR), Weighted Linear Combination (WCL) and Ground Water Potentiality*

INTRODUCTION

Ground water is a dynamic and replenishing natural resource, which forms the core of the ecological system. But in hard rock terrains, availability of Ground Water is of limited extent. Agricultural is main stay in India with 69 % of population depending on it. Poor knowledge about this resource, because of its hidden nature and its occurrence in complex subsurface formation is still a big obstacle to the efficient management of this important resource. The varying nature of ground water potentiality and Agricultural drought is a recurrent phenomenon in the western part of West Bengal. Now a day's Agricultural drought is also a frequent phenomena in West Bengal. It occurs when soil moisture and rainfall are inadequate during the growing season to support the healthy crop growth to maturity and cause extreme crop stress and wilt. Such condition is the outcome of lowering of ground water level and its less accessibility to various activities. The study of ground water potentiality zones of the area will reveal a proper idea about the nature of ground water and will contribute the knowledge to prepare a suitable land use planning map for various socio-economic purposes.

The integrated remote sensing and GIS based study has facilitated to delineate the ground water potential zones by analyzing various phenomena related to land and water resources. According to Saraf et al., (1998) GIS helps to integrate conjunctive analysis of large volumes of multidisciplinary data, both spatial and non-spatial. Jones, 1986; Sinha et al., 1990; Chi and Lee, 1994; Bahuguna et al., 2003; and Kumar et al., 2007 studied and also integrated different thematic data layers such as topography, lithology, geological structures, depth of weathering, extent of fractures, slope and drainage pattern with the help of geographic information techniques to delineate ground water potential zones. In the present study, six ground water potential influencing factors, i.e. geology, relief, slope, geomorphology, drainage, and land use/land cover are taken into account as thematic data layers to prepare ground water potentiality map of the Kangshabati Irrigation Command Area by using Analytical Hierarchy Process (AHP). The analytical hierarchy process (AHP)/Multi Criteria Decision Making Process (MCDMP) is an important approach in the field of decision making system, developed in the late 1970s by Thomas Saaty, which deals with complex, unstructured, and multi-criteria decisions. It presents a flexible and easily understandable way of analyzing complicated problems, and allows ideas and solving problems by making approximate assumptions. So, it has a very high ability to structure complexity and exercise judgment. This is a

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decision support system designed to seek optimum decision making for a complex circumstance through hierarchical structure, which is comprised of targets to be attained, various criteria for decision making and alternatives to be selected (Yang et al, 2006). The AHP overcomes the problems with arbitrary weights and scores approaches, by its ability to enable decision-makers to derive ratio scale priorities or weight as opposed to arbitrarily assign them (Yalcin, 2007). Analytical Hierarchy Process (AHP)/MCDMP is a semi-quantitative method, which includes a matrix-based pair-wise comparison of various ground water contributing factors to determine prioritize class ranking value and prioritized factors weighted value, and to prepare the ground water potentiality map of Kangshabati Irrigation Command Area by performing the weighted linear combination (WLC) model. Prioritized class ranking value and prioritized factors weighted value (principal eigenvectors) for individual thematic data layers and all data layers with consistency checking (Consistency ratio, CR) is accomplished by developing pair-wise comparison matrix as described by Saaty (1990, 1994), and Saaty and Vargas (2001).

The study area area lies at Latitude of $20^{\circ}00'00''\text{E}$ to $23^{\circ}10'00''\text{N}$ and Longitudes of $86^{\circ}10'00''\text{E}$ to $87^{\circ}10'00''\text{E}$ (Figure 1) with an aerial extent of 9632.3 km covering Survey of India Topo-sheet 73 I, 73 J, 73 M and 73 N at 1:250,000 scale in the State of West Bengal, India.

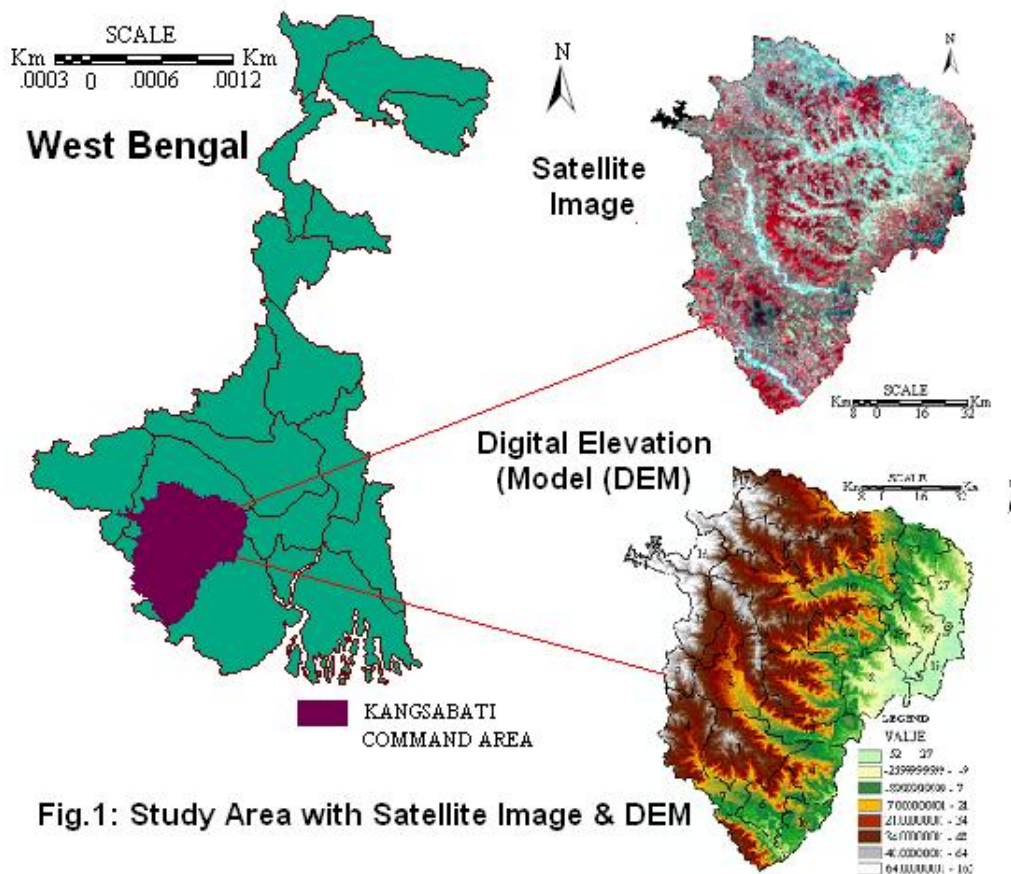


Fig.1: Study Area with Satellite Image & DEM

MATERIALS AND METHODS

To carry out the study and to prepare ground water potential map remote sensing data, others ancillary data, GIS Software (ERDAS IMAGINE 9.0, ARC MAP 9.1), Mathematical Software (MATLAB), and GPS were used in the right sense. The specifications of the satellite and others ancillary data are in detail in the following table1.

Research Article**Table.1: Satellite and Ancillary Data Source**

Satellite Data Specification						
	PAT H	RO W	DATE – OF - PASS		SENSOR-LANDSAT TM	
LANDSAT T 7	139	44& 45	26 TH	November	Spatial Resolution	30M
			2007		Radiometric Resolution	8 BIT
			11 TH	October 2007	SWATH (Km.)	185
					Temporal Resolution	16 DAYS
			20 TH	November	Spectral Bands (µm)	B:0.45-0.52; G: 0.52-
			2009			0.61; R: 0.63-0.69;
			8 TH	October 2009		NIR: 0.77-0.90;
					SWIR: 1.55-1.75;	
					TIR: 10.5-12.5; MIR:	
					2.09-2.35; PAN: 0.52-	
					0.90	
Ancillary Data Used						
DATA			SOURCE			
Toposheets			Survey of India toposheets of West Midnaore region - at scale 1:250,000(toposheets no: 73 J,73 N,73 M)			
District Planning Map			National Atlas Thematic Mapping Organization.			
Geomorphology Map			Geological survey of India			
Soil Map			NATMO			
Geology Map			Geological survey of India			
District Statistical Handbook, 2007			Bureau of Applied Economics & Statistics			
LANDSAT TM, path – 139, row – 44 & 45			ftp://ftp.glcf.umd.edu/glcf/Landsat/WRS2/p139/r044/L5139044_04420061117.TM-GLS2005/			

Creation of thematic data layers (Slope Map, Relief Map, Soil Map, Geological Map, Geomorphological Map, Drainage Density Map, and Land use/Land cover Map)

The present study goes through the analysis of various geomorphic maps and their role in the distribution of ground water potentiality. At first the corresponding Topo-sheets are georeferenced to the Projection - U.T.M. Spheroid: WGS - 84, Datum: WGS – 84, and Zone – 45. Then it is digitized at 10 m interval to generate DEM. The *slope* and *relief map* are derived from DEM (Figure 2a and 2b). The collected *soil map*, *geological map*, and *geomorphological map* from NATMO and GSI are rectified with the help of corresponding toposheet by double image rectification in ERDAS Imagine (9.0). The study area is dominated by Lateritic soil, Older and Younger Alluvial soil, Red Gravel soil and Red Sandy soil (Figure 2c). The area is classified into four individual geological units i.e. Fine & Medium Sands, Unconsolidated Sands, Silt and Clay, Fragment of Peebles & Boulder, Granite Gneiss, Quartzite and Mica Schist (Figure 2d). The different types of Geomorphological features were found in the study area such as Floodplains, Upland Plains, Badlands, Duricrust, Paradelatic fan surfaces, Pediments, Pediplains, Ridges and Hills (Figure 2e). *Drainage network* is delineated by using satellite images to visualize the areas of sheet flow/channel flow and the area was classified into different drainage density classes, viz. very high, high, moderate, low and very low (Figure 2f). After the extraction of different blocks of the study area from the satellite image (FCC) with the help of AOI tools in the ERDAS IMAGINE software a supervised classification was carried out to obtain various *land use/land cover* classes i.e., cropland, wet land, barren land, dense forest, degraded forests, and sandbank etc. (Figure 2g). These pre-field classifications are made to plan the field survey for land use/ land cover data collection.

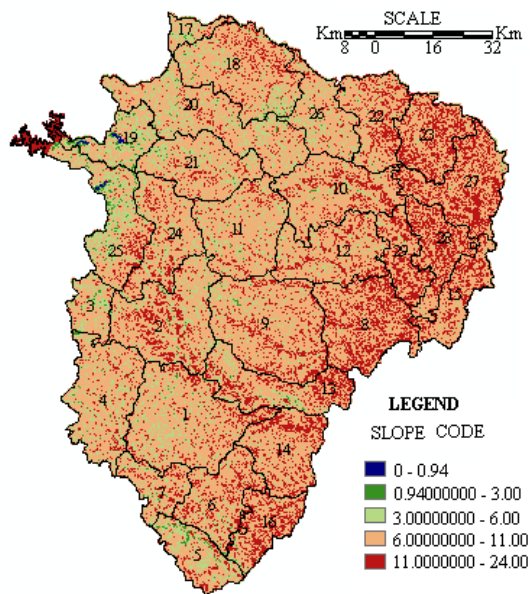


Fig.2a: Slope Map.

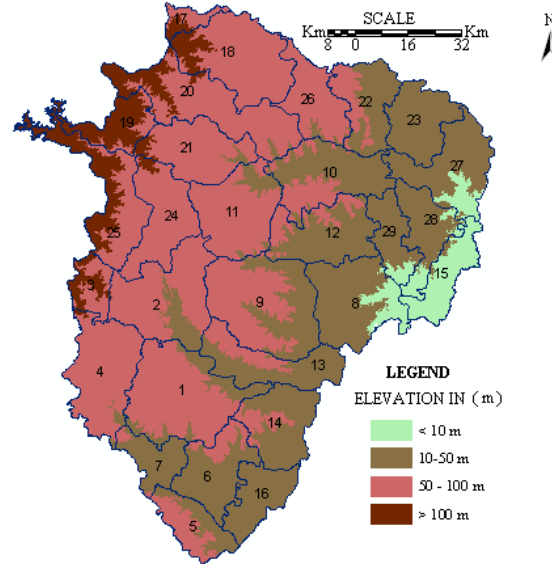


Fig.2b: Relief Map.

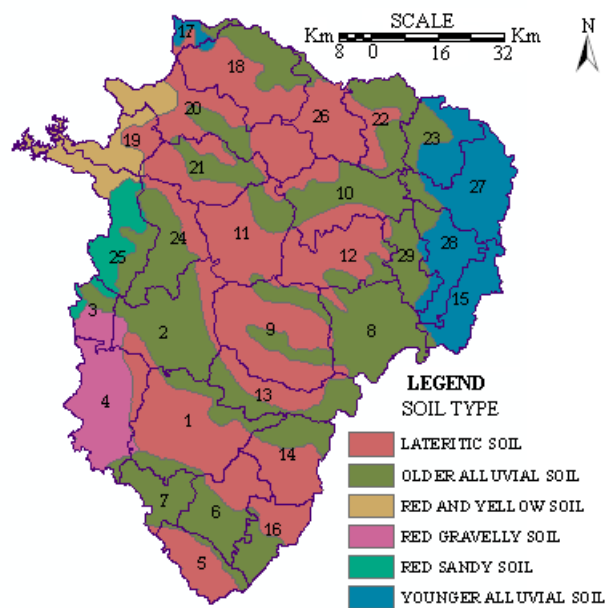


Fig.2c: Soil Map.

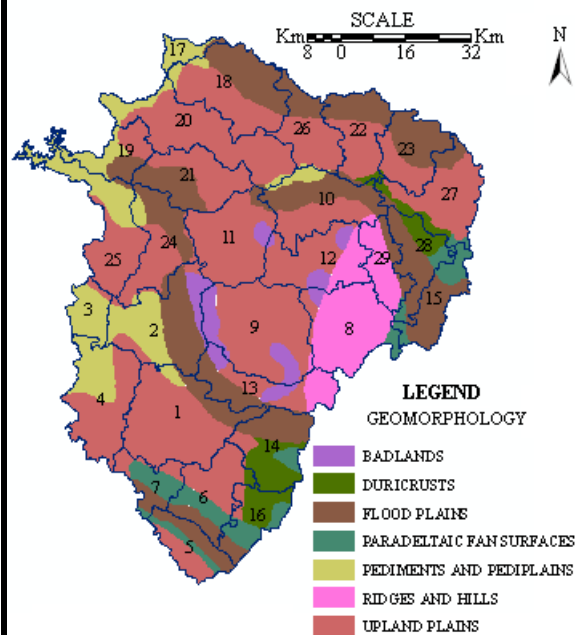


Fig.2d: Geomorphological Map.

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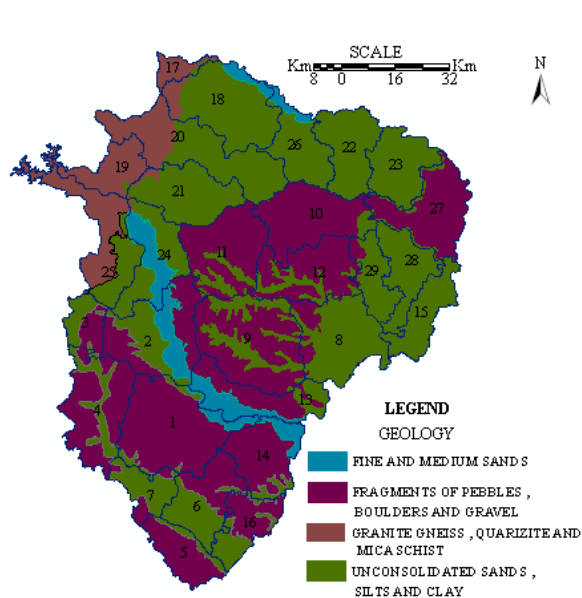


Fig.2e: Geological Map.

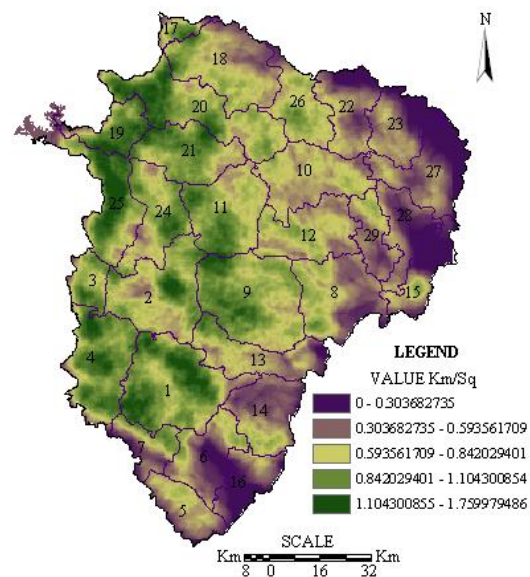


Fig.2f: Drainage Map.

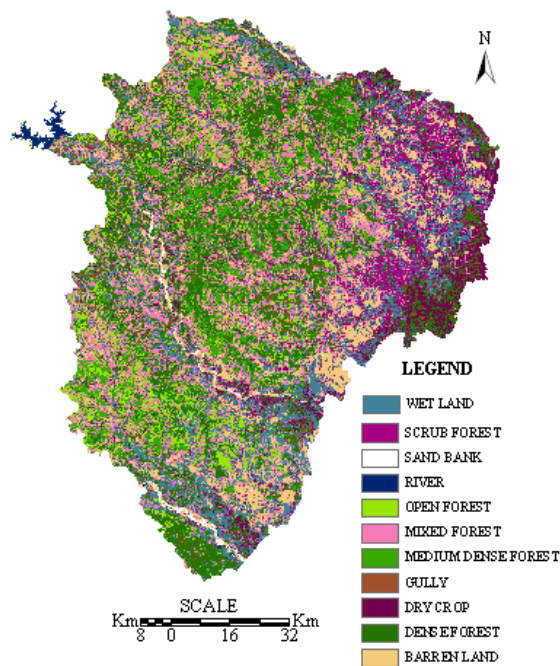


Fig.2g: Land use/Land cover Map.

Analytical Hierarchy Process (AHP)

In the AHP, different factor preference and their conversion into numerical value is made with the help of comparative oral judgment and synthesis of priorities (Table.2). In this method, the preference of a factor effecting the ground water condition is compared with the other factor to derive the priority rates (principal eigenvectors), and for this, a pair wise comparison matrix is constructed carefully.

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Table 2: Scale of preference between two parameters (Saaty, 2000)

Scale	Degree of preference	Explanation
1	Equally	Two activities contribute equally to the objective.
3	Moderately	Experience and judgement slightly to moderately favour one activity over another.
5	Strongly	Experience and judgement strongly or essentially favour one activity over another.
7	Very Strongly	An activity is strongly favoured over another and its dominance is showed in practice.
9	Extremely	The evidence of favouring one activity over another is of the highest degree possible of an affirmation.
2, 4, 6 and 8	Intermediate values	Used to represent compromises between the references in weight 1, 3, 5, 7 and 9.
Reciprocals	Opposites	Used for inverse comparison.

Couple/pair Comparing of all the ground water influencing factors, their prioritized rating and consistency checking

For the construction of couple comparing matrix of all the individual factors, each class/category is rated against every other class/category by assigning a relative dominant value ranging between 1 and 9. The value also varies between the reciprocals $\frac{1}{2}$ and $\frac{1}{9}$ for inverse comparison. Then, arithmetic mean method is used to calculate each alternative prioritized class/category rating value/mean value/eigenvalue of all ground water influencing factor. In the same way, prioritized factor rating value/weighted mean value/thematic map rating value for each factor is also calculated to perform weighted linear combination. Another appealing feature of the AHP is the ability to evaluate pair-wise rating inconsistency. The eigenvalues enable to quantify a consistency measure which is an indicator of the inconsistencies or intransivities in a set of pair-wise ratings. Saaty (2000) presented that for a consistent reciprocal matrix, the largest eigenvalue λ_{Max} is equal to the number of comparisons n .

In AHP, an index of consistency, known as the CR (consistency Ratio), is used to indicate the probability that the matrix judgements were randomly generated (Saaty, 1977).

$$CR = CI/RI \dots\dots\dots (eq.1)$$

Where RI is the average of the resulting consistency index depending on the order of the matrix given by Saaty and CI is the consistency index that is expressed in the following equation.

A measure of consistency, called consistency index CI, is defined as follows:

$$CI = \frac{\lambda_{\text{Max}} - n}{n - 1} \dots\dots\dots (eq.2)$$

Saaty (2000) randomly produced reciprocal matrices using scales 1/9, 1/8, 1/7,.....,1.....8, 9 to evaluate a so called random consistency index (RI). The average RI of 500 matrices is given in the following table.

Table 3: Random Index (Saaty, 2000)

N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	.58	.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.53	1.56	1.57	1.59

According to Saaty, if the value of the CR is smaller or equal to 10%, the inconsistency is acceptable, but if the CR is greater than 10%, the subjective judgement needs to be revised (Saaty, 1977). In the present study, several times subjective value judgements were made to develop all the matrices more consistent. Here, an example of couple comparing matrix to derive prioritized class rating value for different geomorphic units is given (Table.4) and others matrices for all ground water influencing factors have been developed to obtain prioritized class rating value/eigenvector. Then another matrix was developed to estimate prioritized factor rating value where each factor is rated against other factors.

Application of Weighted Linear Combination Model and Ground Water Potential Map

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In the MCDNA, ground water potentiality index value (GWPI-M) is derived using weighted linear combination model (Voogd, 1983) for each pixel by summation of each factor's weight (W_i) multiplied by class weight/ rating (R_i) of each referred ground water influencing factor, which is ascribed below.

Table 4: Developed matrix for Geomorphology

Geomorphic Units	1	2	3	4	5	6	7	Prioritized class rating
Duricrust	1	1/7	1/6	1/5	1/4	1/3	1	0.0373
Ridges and hills.	7	1	1/5	1/4	1/3	1/2	1	0.0834
Upland plains	6	5	1	1/3	1/2	2	3	0.1864
Paradeltaic fan surfaces	5	4	3	1	1/2	2	4	0.2466
Flood Plains	4	3	2	2	1	3	4	0.2723
Pediments and pediplains	3	2	1/2	1/2	1/3	1	5	0.1239
Badlands	1	1	1/3	1/4	1/4	1/5	1	0.050

CI= 0.1244; R.I (Random Index) = 1.32 and CR= 0.0942 (consistent).

$$GWPI(M) = \sum_{i=1}^n (W_i \times R_i) \dots\dots\dots (eq.3)$$

To prepare the ground water potential zone map of Kangshabati Irrigation Command Area, derived 'M' values are classified into 4 zones by using natural breaks algorithm. The 'M' value varies from '0.03' to '0.35'. Higher the value of 'M', excellent is the ground water prospect and vice versa.

Ground Truth Verification

The field survey was carried out for 5 days in the month of March' 2010 to obtain depth of the wells which indicate the ground water condition from 28 training sites of the study area following simple areal random sampling for the accuracy assessment of the prepared ground water potentiality map. Field work has been accomplished in consultation with GPS reading, satellite imagery, SOI topo-sheets. In the present work, the depth of having 0.0m-2.5m, 2.5m-5.0m, 5.00m-7.50m and more than 7.50m were considered as excellent, good, moderate and poor ground water potentiality. Basically, the true data were derived from ground truth verification with the help of GPS from 28 sites. Simultaneously, a set of randomly selected 26 reference pixels points from the classified image corresponding to the true data were used for evaluating the validity of ground water potentiality map (Congalton, 1991).

RESULTS AND DISCUSSION

The calculated consistency ratio (CR) of slope, relief, soil, geomorphology, geology, drainage, land use/land cover and all data layers are 0.04, 0.09, 0.05, 0.09, 0.06, 0.05, 0.03 and 0.09 respectively which proves the preferences applied to prepare couple comparing matrixes are consistent. The estimated prioritized factor rating value/principal eigenvector for all data layers reveals that geomorphology (0.43), relief (0.24), slope (0.13) and land use/land cover (0.09) are the four most important influencing factors for ground water prospect over the area (judged from factor weights). On the basis of derived ground water potentiality index value, Kangshabati Irrigation Command area is divided into 4 ground water potential zones i.e. excellent, good, moderate and poor (Figure 3). Most of the area of the Blocks Ghatal (15), Binpur – I (2), Kotalpur (23), Joypur (22), Midnapore (13), Garbeta (10) and Chandrakona – I (28), are experiencing excellent ground water potentiality. Middle part of the Kangsabati Command area consisting the blocks of Garbeta – II (11), Salboni (9), Keshpur (8), Garbeta – III (12), Jhargram (1) Jamboni (4), Khatra (19), Onda (18), Taldangra (20), and Raipur (25), are recognized as moderate to good Ground Water potential condition. Poor Ground Water Potential Condition is found in the blocks Keshpur (8), Kharaghpur II (14), Keshiary (16), and Garbeta –III (12). It is assumed that the Command area is characterized as Good to Excellent Ground Water. North Eastern and South Central part are providing Good Ground Water Potentiality due to the existence of adequate drainage networking system.

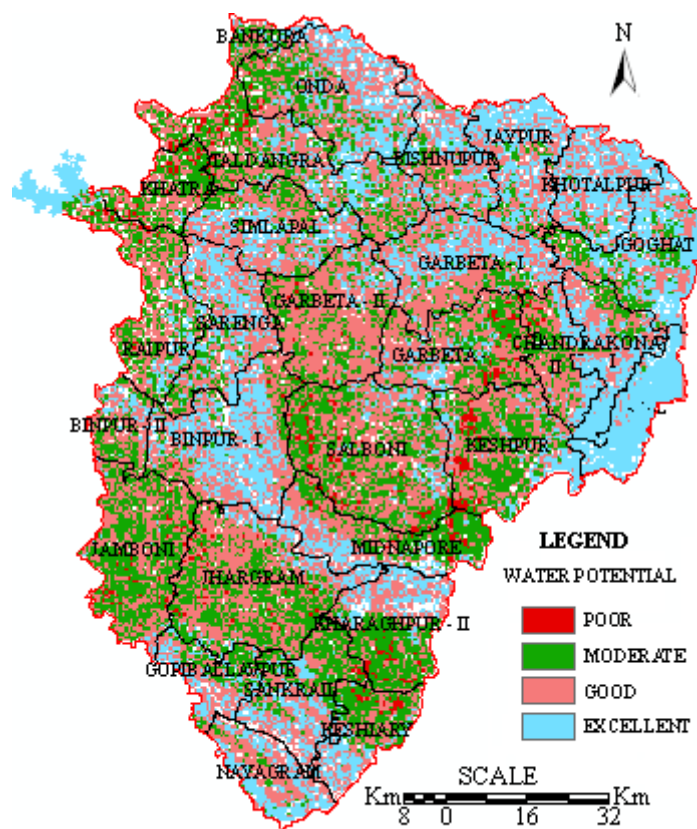


Fig.3: Ground Water Potential Zones.

Table 5: Groundwater Prospect Zones in the Command Area

Groundwater prospects zone	Area (km ²)	Area (%)
Excellent	29.41	27.74
Good	38.64	36.45
Moderate	30.54	28.87
Poor	7.75	7.31

The Eastern and Northern parts of the area with gentle slope registered with good to excellent ground water condition covering the blocks of Joypur (22), Kotalpur (23), Goghat (27), Chandrakona - I (28), Chandrakona - II (29), Binpur - I (2), Midnapore (13), Kharagpur -II (14), Keshpur (8), Ghatal (15), Garbeta - I (10), and Salboni (9). Extreme eastern part of the area is characterized by the elevation of below 50 m and is convening the blocks of Kotalpur (23), Goghat (27), Chandrakona - I (28), Ghatal (15), Chandrakona - II (29), Garbeta- III (12), Keshpur (8), Midnapore (13), Kharagpur (14), Keshiary (16), Gopiballavpur (7) and Sank rail (6) where the ground water prospect is very high. Laterite soil dominated blocks such as Nayagram (80%), Salboni (80%), Garbeta - II (70%), Garbeta - III (90%), Onda (70%), Bishnupur (95%), Simlapal (60%), Taldangra (60%), and Jhargram (60) of the command area experienced moderate to low level ground water potentiality. Older alluvial soil offers excellent ground water potentiality. Red and Yellow soil of Raipur, Khatra and Taldangra. Red gravelly soil of Jamboni, Binpur - I, and Binpur - II and Red sandy soil of Raipur and Binpur -II experiences low ground water potential condition. Younger alluvial soil, covering the blocks of Ghatal, Bankura, Chandrakona - II, Goghat, Kotalpur and some parts of Chandrakona -I, Joypur and Taldangra contributes excellent ground water potentiality. Fine and medium sand and unconsolidated sand-silt-clay are associated with good to excellent ground water potential condition. Geomorphologically, Upland plain is spread out all

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over the area and more than 60 % area of Taldangra (20), Jhargram (1), Sarenga (24), Raipur (25), Bishnupur (20), Goghat (27), Joypur (22), Simlapal (21), 90 % area of Garbeta – II (11), 80 % area of Jamboni and Salboni (9) with good ground water potentiality. Badland topography is found in Binpur-I, Keshpur, Salboni, Garbeta-II, Garbeta-III and Midnapore where the ground water potentiality is low. Flood plains area reveals an excellent ground water potentiality. The area covered by duricrusts with low ridges and hills in Kharaghpur II, Keshiary, Chandrakona - I and Goghat registered with low ground water potentiality. Western and South Western part of Kangsabati area are dominated by very high drainage density with severe soil erosion. On the other hand East and South East and North East marginal part is attributed as low drainage density and good ground water potential condition. Such condition is also covering the blocks of Sankrail, Kharaghpur II, Ghatal, Keshiary, Chandrakona I, and Goghat. Middle and Southern part is characterized as moderate level of drainage density and moderate ground water potentiality. Kangshabati Irrigation Command Area (KICA) is classified in to major eight Land use pattern i.e. crop land, Scrub forest, Dense forest, Open forest, Medium dense forest, Mixed forest, Barren land, and Wet land. The middle most part is basically covered by dense forest, Medium dense forest and Open forest. Extreme Eastern and south Eastern part of the area is experienced as the land of Dry crops, Scrub forest, mixed forest and wetlands. Northern and Western part is attributed as the diversified land use pattern. In terms of Ground Water hydrology the area covering dry crop, scrub forest, mixed forest, and wet land are related with good and excellent ground water prospect and on the other hand, barren land and dense forest experience moderate to poor ground water potentiality.

Accuracy Result

The basic idea is to compare the predicted classification of each pixel with the actual classification and the basic goal of the accuracy study is to quantitatively determine how effectively pixels were grouped

Table 6: Accuracy Assessment/Comparison of landslide susceptibility with field data

Class name (Depth of well in m.)	Classified total	Number correct	Producers Correct	Users Accuracy	Accuracy Total.
Excellent (0.00-2.5)	12	11	11	91.67%	100.00%
Good (2.5-5.00)	2	2	2	100.00%	100.00%
Moderate (5.00-7.5)	11	11	10	90.91%	90.91%
Poor (>7.50)	3	3	3	100.00%	100.00%
Total = 28 28 26					
Overall classification Accuracy = 92.86%					
Overall Kappa Statistics = 0.8919					

into the correct land cover classes. The random points are compared with the classification map. When the random points and classification match, then the classification of that pixel is considered accurate. Classification accuracy in a broad sense refers to the correspondence between classification of remotely sensed data and actual observations on the field. The classification accuracy of the present work is 70.37%.

Conclusion

In the present study, ground water prospect of the Kangshabati Irrigation Command Area (KICA) has been analyzed with the help of Remote Sensing and GIS. Large part of the study area suffers from severe drought condition and the ground water zonation map of the Command Area will contribute a lot of help and knowledge about the hydrology to the concerned authorities engaged in Land use planning. Basically, western part of the Command Area consisting the blocks of Salbani, Sarenga, Binpur, Raipur, Nayagram, Kotalpur, Khatra, Onda, Jaipur, and some parts of Garbeta-I, Garbeta-II, Garbeta-III with moderate to low ground water potential condition should be immediately paid much attention by Water Resource Planners for ensuring diversified agricultural practice based on ground water prospect. Besides, water resource preservation policies/technique should also be applied to get rid of the problems of water in deficient rainfall year considering the ground water potential zones map of the KICA.

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The prepared ground water potential map reveals that Kangshabati Irrigation Command Area is dominated by good (36.45%) ground water prospect, followed by moderate (28.87%), excellent (27.74%) and poor (7.31%). Overall study concludes that the floodplains and paradeltaic fan surfaces contribute much ground water prospect part of the Command Area. As the Kangshabati Irrigation Command area is an undulating terrain, the low lying area may provide suitable sites for the construction of reservoir which can supply water to water deficient area through proper irrigation system during summer/dry season for agricultural practice. Besides, the drainage network analysis indicates that the area is fit for the construction of check dams at the confluence point of several streams.

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