
Mapping of Groundwater Potential Zone Based on Remote Sensing and GIS Techniques: A Case Study of Kalmykia, Russia

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Abstract—Around one-third of the world’s population drinks water from groundwater resources. Of this, about 10 percent, approximately 300 million people, obtains water from groundwater resources. This study identify and mapping of groundwater potential zone for growing population, irrigation and industrial development, combining with remote sensing (RS), geographical information system (GIS) and field data for hydrological research in Kalmykia, Russia. Various thematic layers (i.e. land use/cove, soil, geomorphology, lithology, elevation, slope, rainfall, normalized difference vegetation index (NDVI), drainage density, lineament density, degraded land, forest, relief, vegetation, surface water body, land use, agriculture, flow accumulation, flow direction and base map) wear used along with existing maps to prepare groundwater potential zone (GWPZ) map. Weights were assigned to all above factors according to their effectiveness, sensitivity and relevance to ground water potentiality. Furthermore the resulting GWPZ map has been classified into five classes, named very high, high, moderate, low and very low based on hydro-geomorphological condition, covering 0.93, 11.65, 35.45, 43.20 and 8.77% area respectively. The results show that most part of areas with favorable lithology, soil texture, vegetation, slope, optimum rainfall condition has a high potential for groundwater. The results provide significant information and can be use by local authorities for groundwater exploitation and management.

Keywords: groundwater potential zone, remote sensing, GIS, ArcGIS, DEM

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1. INTRODUCTION

When we think about water source, we think about lakes, rivers and streams; in other words, surface water. However, of all of the usable freshwater in the world, approximately 97 percent of it is groundwater. According to the United Nations, 10 million cubic kilometers of water are stored underground. On earth 97.2% water is salty and only 2.8% water as fresh water, in that surface water represents 2.2% and 0.6% as groundwater. Groundwater accounts for 26% of global renewable fresh water resources but the main problem is to find out it in terms of quantities and quality, which can be economically utilize [1, 2]. The groundwater demand is continuously increasing due to growing population, industrial development and expanding irrigated area. Globally, around 36% water use for domestic purpose, 42% for agriculture and 27% industrial purpose [3].

With the advance in space technology, now it is possible to employ remote sensing and GIS to identify and mapping groundwater potential zones in a large and inaccessible area. The important thing of remote sensing based groundwater exploration is to demarcate and delineate all possible features connected with localization of groundwater [4, 5]. These features are extracted from the thematic details obtained from topographic sheets on the desired scale [6]. The use of conventional methods such as geophysical, statistical or geostatistical techniques, numerical modeling etc have several limitations for groundwater management due to lack of adequate data. Frequent and long term monitoring of groundwater potential zone by conventional methods are expensive, laborious, time consuming and destructive but remote sensing and GIS is very convenient [4]. Satellite data produce quick and suitable guideline and information about diversified factors governing direct or indirectly the occurrences and movements of groundwater. In addi-

tion, GIS contributes a distinguished work environment to deal extensive and complex spatio-temporal data efficiently [7, 8]. The main aim of this research work is to apply an integrated approach of RS and GIS technology to develop thematic data layers for identification and mapping of GWPZ based on various groundwater potential parameters in Kalmykia, Russia.

2. DESCRIPTION OF THE STUDY AREA

The Republic of Kalmykia is a federal subject of Russia (a republic). As of the 2014 Census, its population was 282021. Kalmykia is the only region in Europe where Buddhism is the most practiced religion, with Buddhists being the plurality of the population. Elista, the capital of the republic, has of late, gained an international reputation for international chess competitions. The republic is located in the southwestern part of European Russia and borders, clockwise, with Volgograd Oblast in the northwest and north, Astrakhan Oblast in the north and east, the Republic of Dagestan in the south, Stavropol Krai in the southwest, and with Rostov Oblast in the west. It is washed by the Caspian Sea in the southeast. The length of the territory from north to south is 458 km, from west to east—423 km. Its extreme coordinates are 41°38' and 47°34' east longitude and 48°15' and 44°45' north latitude. The region is located in the zones of steppes, semi-deserts and deserts and covers an area of 75900 km², which is larger than the territory of such states in Western Europe as Belgium, Denmark, Switzerland and the Netherlands.

A small stretch of the Volga River flows through eastern Kalmykia. Other major rivers include the Yegorlyk, the Kuma, and the Manych. Lake Manych-Gudilo is the largest lake; other lakes of significance include Lakes Sarpa and Tsagan-Khak. In all, however, Kalmykia possesses few lakes. Kalmykia has a cold semi-desert climate, with hot and dry summers and cold winters with little snow. The average January temperature is -5°C (23°F) and the average July temperature is $+24^{\circ}\text{C}$ (75°F). Average annual precipitation ranges from 170 millimeters (6.7 in) in the east of the republic to 400 millimeters (16 in) in the west. The small town Utta is the hottest place in the whole of Russia. On July 12, 2010, during a significant heatwave affecting all of Russia, an all-time record-high temperature was observed at 45.4°C .

Agriculture, food processing, coal, oil and natural gas are main economic sector in Kalmykia. Annual budget: revenues and expenditures: about \$100 million. Annual oil production: about 200000 metric tons. As most of Kalmykia is arid, irrigation is necessary for agriculture. The Chernye Zemli Irrigation Scheme in southern Kalmykia receives water from the Caucasian rivers Terek and Kumavia a chain of canals: water flows from the Terek to the Kuma via the Terek-Kuma Canal, then to the Chogray Reservoir on the East Manych River via the Kuma-Manych Canal, and finally into Kalmykia's steppes over the Chernye Zemli Main Canal, constructed in the 1970s. The republic's wildlife includes the saiga antelope, whose habitat is protected in Chyornye Zemli Nature Reserve.

3. MATERIALS AND METHODOLOGY

To complete this work, following data and software's were used:

- Landsat-8/OLI (Operational land imager), acquisition date 24/08/2017.
- Digital Elevation Model (DEM) from ASTER satellite (ASTER-GDEM) with 30m spatial resolution.
- TRMM (tropical rainfall measuring mission): for rainfall data.
- Image processing software: ERDAS.
- GIS software: ArcGIS.
- Maps prepared with the help of satellite data, ancillary data, topographic maps, field data and from specific government departments were: land use/cove, soil, geomorphology, lithology, elevation, slope, rainfall, normalized difference vegetation index (NDVI), drainage density, lineament density, degraded land, forest, relief, vegetation, surface water body, land use, agriculture, flow accumulation, flow direction and base map.

In methodological aspects first georeferenced the all satellite images in UTM/WGS84 projection system and then remove errors like droplines. Also corrected radiometric corrections and used best band combination and enhancement techniques to identify specific features in false color composite images [9]. Then prepared following maps from Landsat OLI image: agriculture, forest, drainage density, lineament density, land use, land use/cove, surface water, vegetation, normalized difference vegetation index (NDVI), and base map. With the help of ASTER-GDEM, create following maps: digital elevation model (DEM), flow accumulation, flow direction, slope, and relief. Also generate other maps such as lithology,

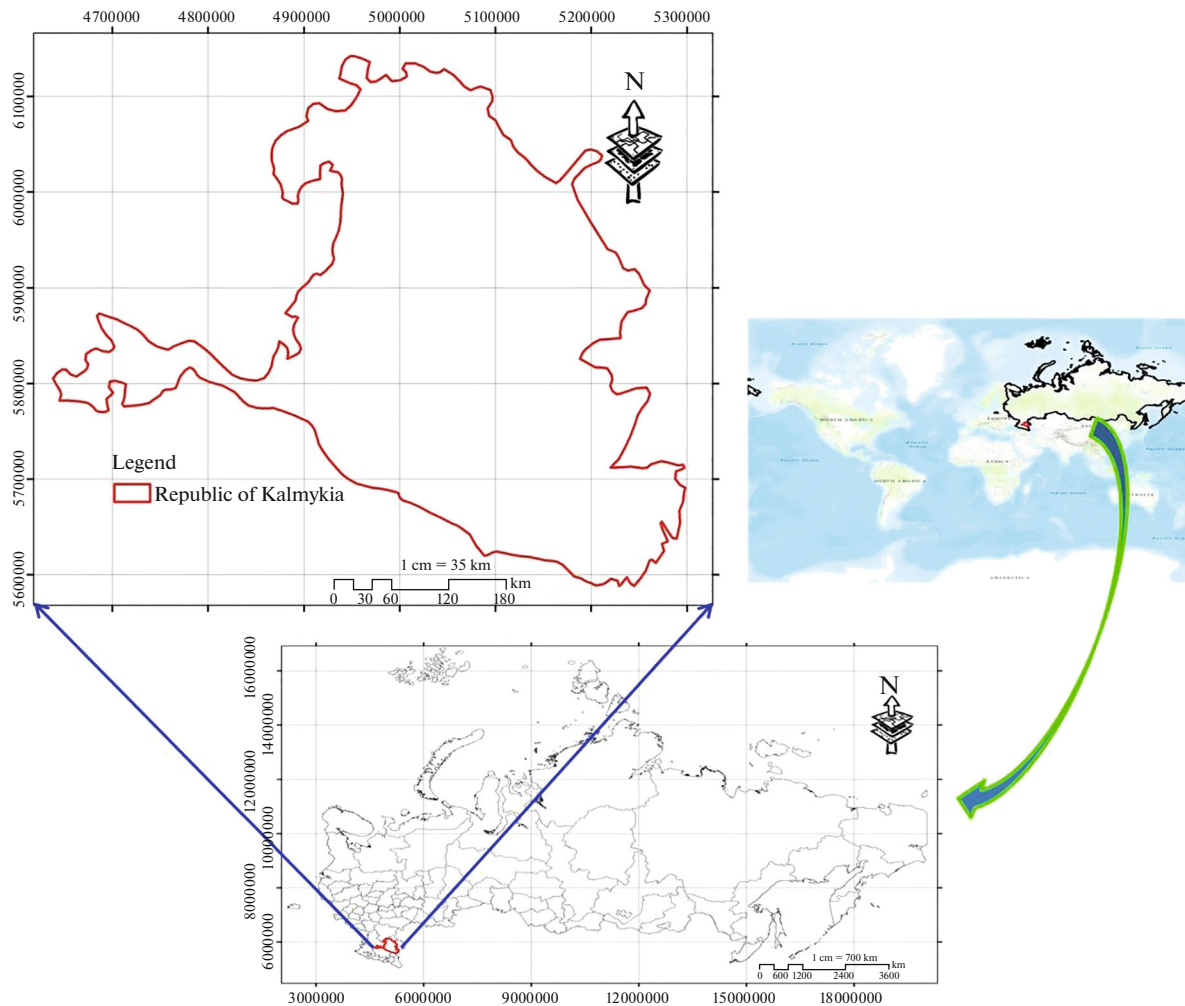


Fig. 1. Location map of The Republic of Kalmykia, Russia.

geomorphology, soil, and degraded land from ancillary data, topography maps and for that contact specific government departments. In last use TRMM satellite data for rainfall map.

All above thematic layers created by RS/GIS were combined by using raster calculate module in ArcGIS software to produce final groundwater potential zone map of Kalmykia, Russia. In this model first each factor has given a weight according to their significance and then each thematic map has been given a weighted value according to its strength of influence/ sensitivity/contribution relevance to the existence of groundwater [2]. Finally, a groundwater potential zone map was created, consisting of five gradational potentiality classes, ranging from very low to very high.

In order to achieve this, all factors were paired [10] with each other (Table 1) as following equation and for that, each factor was given an arithmetic value between 1 and 9 (Table 2), according to its significance when compared to the other factor, with which it formed the pair (Table 1) [6, 10]. So to determine the factors weight first establishes judgment matrices (P) by pairwise comparison as following equation:

$$p = \begin{bmatrix} p_{11} & p_{12} & \dots & p_{1n} \\ p_{21} & p_{22} & \dots & p_{2n} \\ \cdot & \cdot & \dots & \cdot \\ \cdot & \cdot & \dots & \cdot \\ p_{ln} & p_{ln} & \dots & p_{nn} \end{bmatrix}$$

Where P_n denote the n th factor element with P_{nn} being the judgement matrix element.

In the resulting table, an arithmetic value of 9 indicates that a row factor is much more significant than the corresponding column factor with which it has been compared, while an arithmetic value of 1 means that both factors are equally significant (Table 2) [3, 10]. Fraction values are also possible, indicating that a factor is less significant when compared to the factor with which it has been paired [10, 11]. For example, the value of 0.93 (soil column crossed with rainfall line in Table 3), resulted after dividing value 7 (rainfall) with 7.5 from soil column of Table 1 and by this way all factors values were calculated (Table 3). After completion of Table 1, than to gets results (Table 3), the normalized weight was calculated by geometric mean method as following equations:

$$W_n = \left(GM_n / \sum_{n=1}^{nf} GM_n \right).$$

Where the geometric mean of the i th row of the judgment matrices is calculated as:

$$GM_n = n\sqrt{p_{1n}p_{2n} \dots p_{nn}}$$

All factors assigned rating (R), based on field experience and review of existing literature. Factors assigned rating 90 to very high, 70 to high, 50 to moderate, 30 to low and 10 to very low class (Table 4).

The groundwater potential zone (GWPZ) map was mathematically calculated using ArcGIS raster analysis as follow:

$$\begin{aligned} GWPZ &= \sum W_i * R_i, \\ E_f &= W_i * R_i, \\ GWPZ &= \sum (E_f \text{ of all thematic layers}). \end{aligned}$$

Where the E_f = effectiveness of a factor for groundwater potentiality in the study area, W_i = map weight for factor i , R_i = rating value for i factor (weight of inter-map class). Finally calculate groundwater potentiality by adding effectiveness of all thematic maps as above equation.

The resulted quantitative parameters of GWPZ were classified according to the grading method of equal intervals of ArcGIS. This method has been used in the classification of hydrological studies and the classification of vulnerability degrees [4].

4. RESULTS

The nineteen factors for groundwater potentiality mapping (land use/cover, soil, geomorphology, lithology, elevation, slope, rainfall, normalized difference vegetation index (NDVI), drainage density, lineament density, degraded land, forest, relief, vegetation, surface water body, land use, agriculture, flow accumulation, flow direction) are examined separately in the following paragraphs.

4.1 . Land Use/Cover

Land use/cover is one of the most important human induced activity effecting the occurrence and development of groundwater. In land use/cover, groundwater used for irrigation, industry and daily uses etc. LULC map was classified in water body, settlements, vegetation and bare land. We assigned 0.062 weights to LULC map. As water body and vegetation have high possibility of water, so assigned highest rating. While bare and dry land area consider less significant so given lowest rating (Table 4 and Fig. 2).

4.2 . Soil

Soil physical condition or soil texture is directly related to soil properties such as porosity, structure, adhesion and consistency. So soil properties are directly relevant to infiltration and permeability of water, therefor soil characteristics useful to identification of groundwater. Soil layer assigned 0.067 weights for groundwater potentiality (Table 4 and Fig. 2).

4.3 . Geomorphology

To prepare geomorphology map, we used ancillary data, satellite imagery, lithology map, land use map and field data. For satellite image interpretation, we used interpretation key such as tone, texture, color,

Table 1. Pairwise comparison of the factors that affect ground water potentiality

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1. Land use/cover	1	7/7.5	7/6	7/9	7/4	7/6.5	1	7/5	7/4.5	7/4.5	7/3	7/6	7/6.5	7/6	7/8	1	1	7/4	7/4
2. Soil	7.5/7	1	7.5/6	7.5/9	7.5/4	7.5/6.5	7.5/7	7.5/5	7.5/4.5	7.5/4.5	7.5/3	7.5/6	7.5/6.5	7.5/6	7.5/8	7.5/7	7.5/7	7.5/4	7.5/4
3. Geomorphology	6/7	6/7.5	1	6/9	6/4	6/6.5	6/7	6/5	6/4.5	6/4.5	2	1	6/6.5	1	6/8	6/7	6/7	6/4	6/4
4. Lithology	9/7	9/7.5	9/6	1	9/4	9/6.5	9/7	9/5	2	2	3	9/6	9/6.5	9/6	9/8	9/7	9/7	9/4	9/4
5. Elevation	4/7	4/7.5	4/6	4/9	1	4/6.5	4/7	4/5	4/4.5	4/4.5	4/3	4/6	4/6.5	4/6	4/8	4/7	4/7	1	1
6. Slope	6.5/7	6.5/7.5	6.5/6	6.5/9	6.5/4	1	6.5/7	6.5/5	6.5/4.5	6.5/4.5	6.5/3	6.5/6	1	6.5/6	6.5/8	6.5/7	6.5/7	6.5/4	6.5/4
7. Rainfall	1	7/7.5	7/6	7/9	7/4	7/6.5	1	7/5	7/4.5	7/4.5	7/3	7/6	7/6.5	7/6	7/8	1	1	7/4	7/4
8. NDVI	5/7	5/7.5	5/6	5/9	5/4	5/6.5	5/7	1	5/4.5	5/4.5	5/3	5/6	5/6.5	5/6	5/8	5/7	5/7	5/4	5/4
9. Drainage den.	4.5/7	4.5/7.5	4.5/6	4.5/9	4.5/4	4.5/6.5	4.5/7	4.5/5	1	1	4.5/3	4.5/6	4.5/6.5	4.5/6	4.5/8	4.5/7	4.5/7	4.5/4	4.5/4
10. Lineament den	4.5/7	4.5/7.5	4.5/6	4.5/9	4.5/4	4.5/6.5	4.5/7	4.5/5	1	1	4.5/3	4.5/6	4.5/6.5	4.5/6	4.5/8	4.5/7	4.5/7	4.5/4	4.5/4
11. Degraded land	3/7	3/7.5	3/6	3/9	3/4	3/6.5	3/7	3/5	3/4.5	3/4.5	1	3/6	3/6.5	3/6	3/8	3/7	3/7	3/4	3/4
12. Forest	6/7	6/7.5	1	6/9	6/4	6/6.5	6/7	6/5	6/4.5	6/4.5	2	1	6/6.5	1	6/8	6/7	6/7	6/4	6/4
13. Relief	6.5/7	6.5/7.5	6.5/6	6.5/9	6.5/4	1	6.5/7	6.5/5	6.5/4.5	6.5/4.5	6.5/3	6.5/6	1	6.5/6	6.5/8	6.5/7	6.5/7	6.5/4	6.5/4
14. Vegetation	6/7	6/7.5	1	6/9	6/4	6/6.5	6/7	6/5	6/4.5	6/4.5	2	1	6/6.5	1	6/8	6/7	6/7	6/4	6/4
15. Surface water	8/7	8/7.5	8/6	8/9	2	8/6.5	8/7	8/5	8/4.5	8/4.5	8/3	8/6	8/6.5	8/6	1	8/7	8/7	2	2
16. Land use	1	7/7.5	7/6	7/9	7/4	7/6.5	1	7/5	7/4.5	7/4.5	7/3	7/6	7/6.5	7/6	7/8	1	1	7/4	7/4
17. Agriculture	1	7/7.5	7/6	7/9	7/4	7/6.5	1	7/5	7/4.5	7/4.5	7/3	7/6	7/6.5	7/6	7/8	1	1	7/4	7/4
18. Flow accum	4/7	4/7.5	4/6	4/9	1	4/6.5	4/7	4/5	4/4.5	4/4.5	4/3	4/6	4/6.5	4/6	4/8	4/7	4/7	1	1
19. Flow direction	4/7	4/7.5	4/6	4/9	1	4/6.5	4/7	4/5	4/4.5	4/4.5	4/3	4/6	4/6.5	4/6	4/8	4/7	4/7	1	1

Table 2. Scale of relative importance

Definition	Equally important	Extremely less imp.	Strongly less imp.	Less important	Moderately less imp.	Moderately important	Strong important	Very strong imp.	Extremely important
Intensity importance	1	2	3	4	5	6	7	8	9

Table 3. Calculation of factors weight (in combination with Table 1)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	GM	Wn
1	1.00	0.93	1.17	0.78	1.75	1.07	1.00	1.40	1.55	1.55	2.33	1.17	1.07	1.17	0.88	1.00	1.00	1.75	1.75	1.23	0.062
2	1.07	1.00	1.25	0.83	1.87	1.15	1.07	1.50	1.66	1.66	2.50	1.25	1.15	1.25	0.93	1.07	1.07	1.87	1.87	1.31	0.067
3	0.86	0.80	1.00	0.67	1.50	0.92	0.86	1.20	1.33	1.33	2.00	1.00	0.92	1.00	0.75	0.86	0.86	1.50	1.50	1.05	0.053
4	1.29	1.20	1.50	1.00	2.25	1.38	1.29	1.80	2.00	2.00	3.00	1.50	1.38	1.50	1.13	1.29	1.29	2.25	2.25	1.58	0.080
5	0.57	0.53	0.67	0.44	1.00	0.61	0.57	0.80	0.88	0.88	1.33	0.67	0.61	0.67	0.50	0.57	0.57	1.00	1.00	0.70	0.036
6	0.92	0.86	1.08	0.72	1.62	1.00	0.92	1.30	1.44	1.44	2.16	1.08	1.00	1.08	0.81	0.92	0.92	1.62	1.62	1.14	0.058
7	1.00	0.93	1.17	0.78	1.75	1.07	1.00	1.40	1.55	1.55	2.33	1.17	1.07	1.17	0.88	1.00	1.00	1.75	1.75	1.23	0.062
8	0.71	0.66	0.83	0.56	1.25	0.76	0.71	1.00	1.11	1.11	1.67	0.83	0.76	0.83	0.63	0.71	0.71	1.25	1.25	0.88	0.044
9	0.64	0.60	0.75	0.50	1.12	0.69	0.64	0.90	1.00	1.00	1.50	0.75	0.69	0.75	0.56	0.64	0.64	1.12	1.12	0.79	0.040
10	0.64	0.60	0.75	0.50	1.12	0.69	0.64	0.90	1.00	1.00	1.50	0.75	0.69	0.75	0.56	0.64	0.64	1.12	1.12	0.79	0.040
11	0.43	0.40	0.50	0.33	0.75	0.46	0.43	0.60	0.66	0.66	1.00	0.50	0.46	0.50	0.38	0.43	0.43	0.75	0.75	0.53	0.027
12	0.86	0.80	1.00	0.67	1.50	0.92	0.86	1.20	1.33	1.33	2.00	1.00	0.92	1.00	0.75	0.86	0.86	1.50	1.50	1.05	0.053
13	0.92	0.86	1.08	0.72	1.62	1.00	0.92	1.30	1.44	1.44	2.16	1.08	1.00	1.08	0.81	0.92	0.92	1.62	1.62	1.14	0.058
14	0.86	0.78	1.00	0.67	1.50	0.92	0.86	1.20	1.33	1.33	2.00	1.00	0.92	1.00	0.75	0.86	0.86	1.50	1.50	1.05	0.053
15	1.14	1.06	1.33	0.89	2.00	1.23	1.14	1.60	1.77	1.77	2.67	1.33	1.23	1.33	1.00	1.14	1.14	2.00	2.00	1.40	0.071
16	1.00	0.93	1.17	0.78	1.75	1.07	1.00	1.40	1.55	1.55	2.33	1.17	1.07	1.17	0.88	1.00	1.00	1.75	1.75	1.23	0.062
17	1.00	0.93	1.17	0.78	1.75	1.07	1.00	1.40	1.55	1.55	2.33	1.17	1.07	1.17	0.88	1.00	1.00	1.75	1.75	1.23	0.062
18	0.57	0.53	0.67	0.44	1.00	0.61	0.57	0.80	0.88	0.88	1.33	0.67	0.61	0.67	0.50	0.57	0.57	1.00	1.00	0.70	0.036
19	0.57	0.53	0.67	0.44	1.00	0.61	0.57	0.80	0.88	0.88	1.33	0.67	0.61	0.67	0.50	0.57	0.57	1.00	1.00	0.70	0.036

shape and size etc. In final geomorphology map, we assigned 0.053 weights and reclassify whole map in 5 classes based on groundwater possibility (Table 4 and Fig. 2).

4.4. Lithology

Lithology layer assigned 0.080 weights. In lithology fractures, joins, dykes and porosity are influencing features to increase groundwater storage capacity. The sedimentary aquifers with primary porosity have higher groundwater storage capacity. The lithology map was derived from ancillary data and available geological maps. Whole map was divided into 5 classes according to their possibility of storage groundwater capacity (Table 4 and Fig. 2).

Table 4. Rating and weights of factors that used for ground water potentiality mapping

		Class	Class type	Unit	Rating (R)	Weight (W)	Effectiveness
1	Land use/cover	Very high	Water body and settlements	(Unit A)	90	0.062	5.58
		High	Agriculture	(Unit B)	70	0.062	4.34
		Moderate	Vegetation	(Unit C)	50	0.062	3.1
		Low	Dry water body	(Unit D)	30	0.062	1.86
		Very low	Bare land	(Unit E)	10	0.062	0.62
2	Soil	Very high	Marshy saline and solonetzic/solonchaks and Alluvials meadow	(Unit A)	90	0.067	6.03
		High	Chernozems southern and ordinary mycelial calcareous etc.	(Unit B)	70	0.067	4.69
		Moderate	light Chestnuts and Chestnuts solonetzic etc.	(Unit C)	50	0.067	3.35
		Low	Solonetzes	(Unit D)	30	0.067	2.01
		Very low	Browns solonetzic and solonc hacous and sand	(Unit E)	10	0.067	0.67
3	Geomorphology	Very high	Perennial and non-perennial river		90	0.053	4.77
		High	Upland plains and Deeply weathered plains		70	0.053	3.71
		Moderate	Present flood plains		50	0.053	2.65
		Low	Para deltaic fan surface		30	0.053	1.59
		Very low	Mature deltaic plains		10	0.053	0.53
4	Lithology	Very high	Calcareous loess like deposits and losses	(Unit A)	90	0.080	7.2
		High	Eluvium of massive crystal rocks, sandstones, muds	(Unit B)	70	0.080	5.6
		Moderate	Eluvium and diluvium of massive rock	(Unit C)	50	0.080	4
		Low	Marine saline and fixed and non-fixed sand	(Unit D)	30	0.080	2.4
		Very low	Alluvial	(Unit E)	10	0.080	0.8
5	Elevation	Very high	<-6		90	0.036	3.24
		High	25-(-)6		70	0.036	2.52
		Moderate	25-70		50	0.036	1.8
		Low	70-120		30	0.036	1.08
		Very low	>120		10	0.036	0.36
6	Slope	Very high	0-1.3		90	0.058	5.22
		High	1.4-2.4		70	0.058	4.06
		Moderate	2.5-3.9		50	0.058	2.9
		Low	4-6.6		30	0.058	1.74
		Very low	>6.7		10	0.058	0.58
7	Rainfall	Very high	19-29 mm		90	0.620	55.8
		High	12-19 mm		70	0.620	43.4
		Moderate	08-12 mm		50	0.620	31
		Low	04-08 mm		30	0.620	18.6
		Very low	0-04 mm		10	0.620	6.2

Table 4. (Contd.)

		Class	Class type	Unit	Rating (R)	Weight (W)	Effectiveness
8	NDVI	Very high	>0.50		90	0.440	39.6
		High	0.25–0.50		70	0.440	30.8
		Moderate	(–)0.25–0.025		50	0.440	22
		Low	(–)0.50–(–)0.25		30	0.440	13.2
		Very low	<(–) 0.50		10	0.440	4.4
9	Drainage density	Very high	<40		90	0.400	36
		High	40–80		70	0.400	28
		Moderate	80–120		50	0.400	20
		Low	120–160		30	0.400	12
		Very low	>160		10	0.400	4
10	Lineament density	Very high	9.37–11.70		90	0.400	36
		High	7.03–9.36		70	0.400	28
		Moderate	4.69–7.02		50	0.400	20
		Low	2.35–4.68		30	0.400	12
		Very low	0–2.34		10	0.400	4
11	Degraded land	Very high	Water body and settlements	(Unit A)	90	0.027	2.43
		High	Agriculture	(Unit B)	70	0.027	1.89
		Moderate	Irrigation management and drainage network	(Unit C)	50	0.027	1.35
		Low	Arable land-field management pasture	(Unit D)	30	0.027	0.81
		Very low	Pasture-degraded	(Unit E)	10	0.027	0.27
12	Forest	Very high		(Unit A)	90	0.053	4.77
		High		(Unit B)	70	0.053	3.71
		Moderate		(Unit C)	50	0.053	2.65
		Low		(Unit D)	30	0.053	1.59
		Very low		(Unit E)	10	0.053	0.53
13	Relief	Very high	0–1.3		90	0.058	5.22
		High	1.4–2.4		70	0.058	4.06
		Moderate	2.5–3.9		50	0.058	2.9
		Low	4–6.6		30	0.058	1.74
		Very low	>6.7		10	0.058	0.58
14	Vegetation	Very high	Inland waterbody, Southern and Northern dry xerophytic herbs etc.	(Unit A)	90	0.053	4.77
		High	Northern and southern semi shrub, bunch grass	(Unit B)	70	0.053	3.71
		Moderate	Ecological rows of perennial, saltworts, etc..	(Unit C)	50	0.053	2.65
		Low	Saltwort in complex with halophytic sagebrush, Meadow grass etc.	(Unit D)	30	0.053	1.59
		Very low	Sagebrush among grasses (Stipa sareptana, etc.) in complex with sage-brush	(Unit E)	10	0.053	0.53

Table 4. (Contd.)

		Class	Class type	Unit	Rating (R)	Weight (W)	Effectiveness
15	Surface waterbody	Very high	Water body	(Unit A)	90	0.710	63.9
		High		(Unit B)	70	0.710	49.7
		Moderate	Dry water body	(Unit C)	50	0.710	35.5
		Low		(Unit D)	30	0.710	21.3
		Very low		(Unit E)	10	0.710	7.1
16	Land use	Very high	Inland Water bodies, Cropland	(Unit A)	90	0.620	55.8
		High	Cropland (more than 50%) combined with natural forage land, Desert etc..	(Unit B)	70	0.620	43.4
		Moderate	Forest, Irrigated cropland	(Unit C)	50	0.620	31
		Low	Solonchaks, Bogs and barren sand area, Natural meadow forage land	(Unit D)	30	0.620	18.6
		Very low	Desert and semi desert	(Unit E)	10	0.620	6.2
17	Agriculture	Very high	Water and vegetable growing	(Unit A)	90	0.620	55.8
		High	Grain crop (wheat)	(Unit B)	70	0.620	43.4
		Moderate	Seasonal pasture and agriculture	(Unit C)	50	0.620	31
		Low	Area not used in agriculture	(Unit D)	30	0.620	18.6
		Very low	Area used only in seasonal pasture	(Unit E)	10	0.620	6.2
18	Flow accumulation	Very high	<2		90	0.036	3.24
		High	2–3		70	0.036	2.52
		Moderate	3–5		50	0.036	1.8
		Low	5–6		30	0.036	1.08
		Very low	>6		10	0.036	0.36
19	Flow direction	Very high	<2		90	0.036	3.24
		High	2–8		70	0.036	2.52
		Moderate	8–32		50	0.036	1.8
		Low	32–64		30	0.036	1.08
		Very low	>64		10	0.036	0.36

4.5. Elevation

We prepared elevation map from ASTER-GDEM, elevation is directly related to ruggedness of the terrain, which has a major role in the identification of groundwater. A plan area or lower elevation with steep slope has smaller runoff, less drainage, higher infiltration rate so higher possibility of ground water. In the study area high elevation area have high ground water possibility due to higher amount of rainfall. Kalmykia have –103 m lowest and 285 m highest elevation point. The study area can be divided into 5 major classes as (1) higher then >120, (2) 120 to 70, (3) 70 to 25, (4) 25 to –6, and less then <–6. Elevation layer assigned 0.036 weights (Table 4 and Fig. 2).

4.6. Slope

Slope is directly related to groundwater because in high slope, water velocity is high so infiltration rate is low so overall groundwater recharge possibility is low. In other hand in lower sloop, infiltration rate is high due to low water velocity so greater chance of groundwater recharge. Slope map was prepared by ASTER-GDEM data in ArcGIS software and assigned 0.058 weights (Table 4 and Fig. 2).

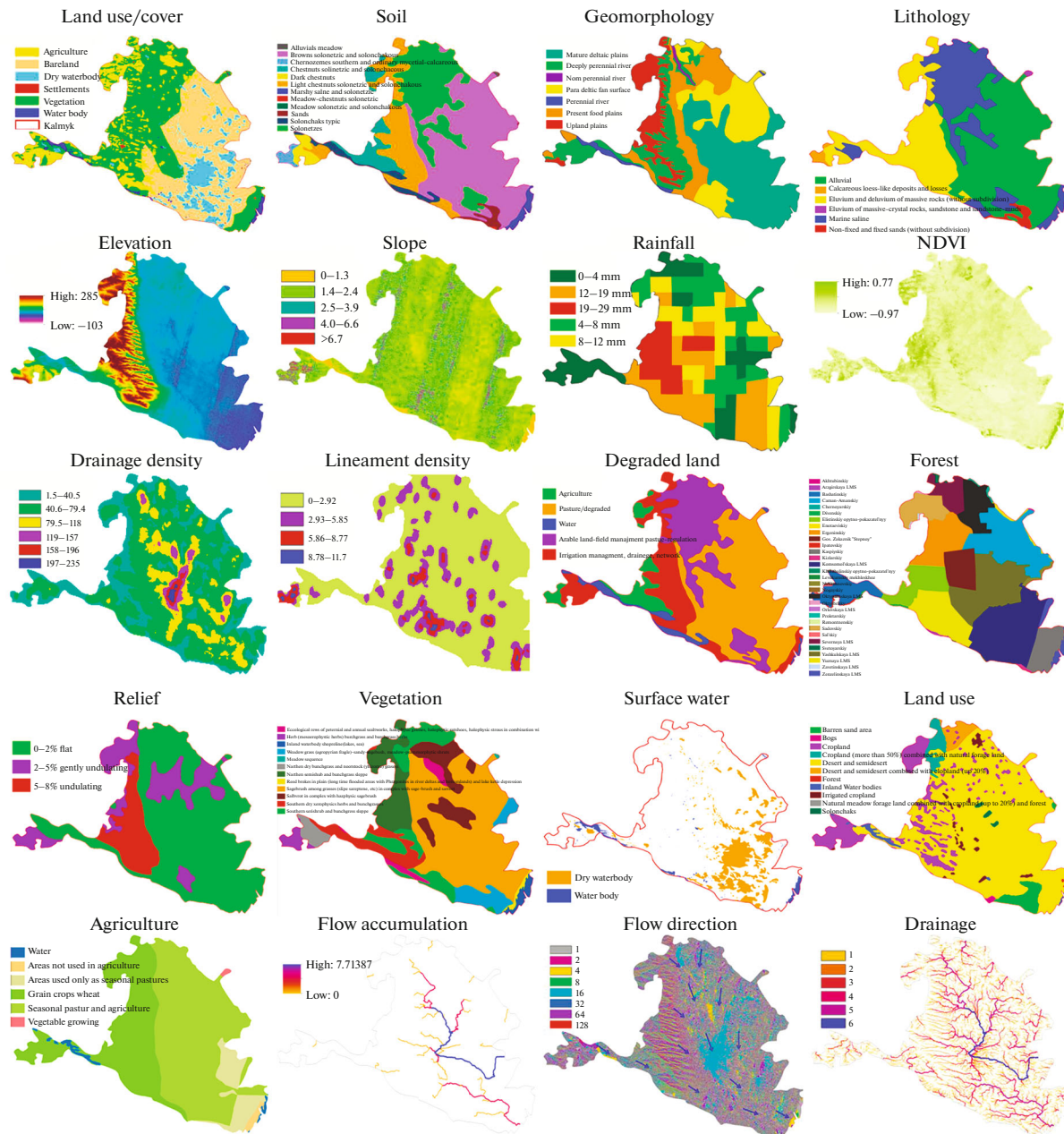


Fig. 2. Thematic layers which used for ground water potential zone mapping.

4.7. Rainfall

Higher rainfalls increase the possibility of higher groundwater potentiality. This is a one of the most important factor and we assigned 0.620 weights to rainfall layer. We use TRMM data for rainfall information and its show 0 to 29 mm mean summer monthly rainfall in the study area. The resulted map was classified into 5 major classes (Table 4 and Fig. 2): 0-4 (very low), 4-8 (low), 8-12 (moderate), 12-19 (high) and 19-29 mm/month (very high). From the rainfall map, it can be observed that higher altitude have high possibility of high rainfall and high groundwater possibility in comparison of low altitude area. Generally 70% rainfall occurs in rainy season and about 60% rainfall return back to atmosphere via evaporation process.

4.8. NDVI

Normalized difference vegetation index (NDVI) is directly related to groundwater possibility because if an area have higher density of healthy vegetation, its show higher possibility of groundwater and vice-versa. NDVI have -1 to $+1$ value and $+1$ ($0.8-0.9$) value represent high density of healthy vegetation and -1 or close to it show no vegetation or desert/drought area. Kalmykia have -0.97 lowest values, which show drought area in north-south part of the study area, whereas highest value is 0.77 which show healthy vegetation or higher possibility of groundwater in north-east direction of the study area. NDVI layer assigned 0.44 weights (Table 4 and Fig. 2).

4.9. Drainage Density

We used ASTER-GDEM data to prepare drainage map and later on create drainage density map via “line density” commend in ArcGIS software and in last reclassify it into 5 classes from very low to very high (Table 4 and Fig. 2). Drainage network produce dendritic pattern, resulting water flow in a homogenous soil surface with same geological conditions. The denser the drainage has the less capacity of groundwater recharge and vice versa. We assigned 0.40 weights to drainage density layer.

4.10. Lineament Density

A lineament is a linear feature in a landscape and show fault feature in underline geological structure. We create lineament feature via 764 band combination of Landsat-8 OLI image in ArcGIS software. After creation of lineament and faults, their density was created in ArcGIS software. Later on reclassify density of lineaments into 5 classes from very low to very high (Table 4 and Fig. 2). We assigned 0.40 weights for groundwater potentiality. It can be noticed that high densities of lineament or fault have high possibility of groundwater.

4.11. Degraded Land

Degraded land is directly related to groundwater because less amount of water is the one of the main cause of degraded land. We classified 5 classes in degraded land map and give higher ranking to water body, irrigated area with low drainage network area. Where pasture and desert area assigned lowest ranking, over all degraded map was assigned 0.027 weights (Table 4 and Fig. 2).

4.12. Forest

A dense forest area is directly related to ground water possibility and whereas open forest or shrub area, lesser possibility of water or indicate desert/drought area. Forest map was classified into 5 classes based on type and density of forest and assigned 0.053 weights (Table 4 and Fig. 2).

4.13. Relief

We prepared relief map from ASTER-GDEM, relief map is directly related to flatness of the terrain, which has a major role in the identification of groundwater. A plan area or lower relief has smaller runoff, less drainage, higher infiltration rate so higher possibility of ground water. The study area can be divided in 5 major classes as (1) higher then >6.7 , (2) 6.6 to 4 , (3) 3.9 to 2.5 , (4) 2.4 to 1.4 , and less then <1.3 . Relief factor assigned 0.058 weights (Table 4 and Fig. 2).

4.14. Vegetation

Vegetation also directly relevant to possibility of groundwater as in study area where is higher possibility of vegetation such as agriculture, forest and plantation show green areas (northwest). In another side less vegetation cover area show desert or drought areas (east-south) have less possibility of groundwater. We classified 5 classes of vegetation based on their health and density and assigned 0.053 weights (Table 4 and Fig. 2).

4.15. Surface Water

Surface waterbody is directly related to groundwater possibility. If an area has higher number of surface waterbodies then it might be higher possibility of groundwater. Surface water assigned 0.71 weights (Table 4 and Fig. 2).

4.16. Land Use

Land use map is differ from land use/cover map as it's indicate naturally or proper utilization of land where land cover map represent all types of feature naturally as well as man-made or artificial features. As land use map near to nature or proper utilization of land so we assigned higher weight in compare of land use/cover. Here land use map assigned 0.62 weights (Table 4 and Fig. 2).

4.17. Agriculture

Agriculture map was generated via Landsat imagery. Higher productive agriculture land has higher possibility of groundwater and the area which is not used for agriculture (pasture and bare land) indicates lesser water availability. Here agriculture layer assigned 0.62 weights (Table 4 and Fig. 2).

4.18. Flow Accumulation

We used ASTER-GDEM data to prepare flow accumulation map in ArcGIS software and reclassify it into 5 classes from very low to very high (Table 4 and Fig. 2). Low accumulation values represent ridge tops so less possibility of groundwater due to low infiltration, steep slope and higher water flow. Whereas higher accumulation values represent valleys and stream channels so higher possibility of groundwater due to high infiltration. Flow accumulation assigned 0.036 weights.

4.19. Flow Direction

Flow direction map gives us the flow across a surface which will always be in the steepest down-slope direction and is used to determine the stream network. Flow direction map created from ASTER-GDEM grid shows the direction of river flow from northeast to southwest and finally reached in Caspian see. We assigned 0.036 weights to flow direction (Table 4 and Fig. 2).

5. GROUNDWATER POTENTIAL ZONING

Finally after combined all above thematic maps, the final groundwater potential zone map of Kalmykia, Russia was generated (Fig. 3). Resulted GWPZ map reveals five distinct classes named as "very high, high, moderate, low and very low groundwater potentiality in the study area. Generally very high and high ground water potential zones have maximum possibility of groundwater. In this area river and waterbodies generally recharge groundwater level. It's also possible if terrain is flat, gentle slope, soft and unconsolidated that it is most suitable for groundwater storage. Around 12% area comes under high and very high groundwater potential zone and it covers a small area in southwest and south part (Fig. 3). The moderate area mainly presents west part of the study area and cover 35.45% of the total area. However, east parts of the study area fall under the low groundwater potential zone, covering 43.20% of the total study area, due to its higher slope, unfavorable geological and geomorphological conditions. This area covers maximum desert part of the study area. Some parts in east and south come under very low water potential zones. Its fully a desert area and also cover hottest place in Russia called Utta city.

In general high vegetation cover area, less slope area, low drainage density area, high flow accumulation, high rainfall, high lineament density, older alluvial plain, floodplain, deeply buried pediplain and unfilled valley are covered by thick alluvium and weathered material. Hence, these areas are marked as high to very high prospect zones for groundwater exploration due to higher infiltration rate. The moderately deep buried pediplain, shallow buried pediplain, low lineament density, medium rainfall and slope are grouped as moderate to high zones and very low lineament density are grouped as moderate to low zones. The piedmont plain, bare land, desert area, low rainfall, hills, linear ridge and inselbergs are grouped as low to very low zones.

To verify the results, we visit two times in the field (February and July 2018) and measure the ground water depth in different wells in the study area. The depth of water was according to GWPZ results. Also derive over all accuracy, producer accuracy and Kappa statistics, which show more than 92% accuracy.

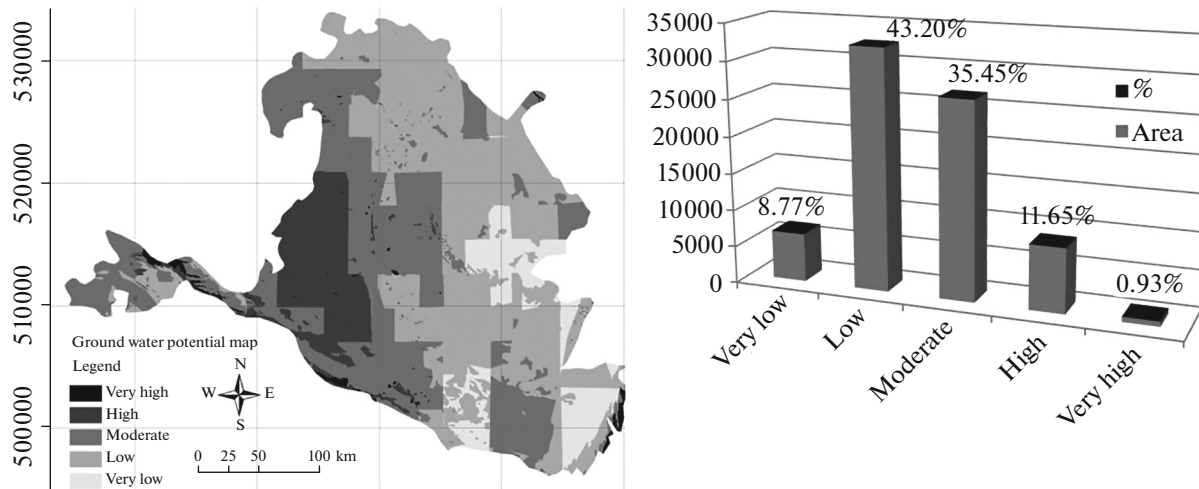


Fig. 3. Resulted groundwater potentiality map and graph.

The groundwater potential zone map can be useful tool to identify new sources of water supply. Other than this, proposed method allows the revision of the weights and rating of factors in order to be suitable for other regions according to their specific characteristics.

The validation of this methodology for GWPZ mapping, through RS/GIS and with the help of field work/ground truth would benefit in future hydrological investigation and field data concerning groundwater recharge and balance etc. Additional uncertainties in mapping the spatial distribution relates to the compatibility between the scale and resolution of the mapping techniques.

6. CONCLUSIONS

In order to sustain long term agriculture, vegetation as well as socio-economic development in Kalmykia, Russia, judicious use of groundwater is necessary. This study concluded that RS/GIS technology with field data and ancillary data can use to identify and monitoring groundwater potential zones. Nineteen factors were used and gave weight according to analytic hierarchy process (pairwise comparison) for the final GWPZ map and integration RS/GIS technology proves to be rather satisfactory option for groundwater mapping and identification. GWPZ map was classified into 5 groundwater potential classes named very high, high, moderate, low and very low covering 0.93, 11.65, 35.45, 43.20 and 8.77% area. The results show that most part of areas with favorable lithology, soil texture, vegetation, slope, optimum rainfall condition has a high potential for groundwater. Identification and selection of suitable number of thematic layers and justifiable assignment weight is the key to the benefit of RS/GIS in determining the potential zone of groundwater resources in compare of old and tradition methods in a country, which have a vast territory like Russia. The flexibility of the method allows the revision of the weights of including factors, so the method could be applied in a wider variety of regions in Russia. These maps can use by engineers, planners and decision makers to allocate, develop and manage groundwater within a national water polices.

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