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Identification of Groundwater Potential Zones Using Remote Sensing, Geographical Information System, and Analytic Hierarchy Process Techniques – A Case Study in the Nerodime Watershed, Kosovo

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ABSTRACT
This research was carried out to analyse the groundwater potential areas in the Nerodime River catchment area. This paper used the standard methodology to determine the potential areas of groundwater resources based on the combated remote sensing, geographic information system, and hierarchical analytical process. In this river catchment area, a total of eight groups of criteria have been selected which have an impact on groundwater storage. Groundwater research would not be possible without the use of various data that have a direct impact on groundwater such as drainage, elevation, geology, land use and land cover, lineament, rainfall, slope, and soil. The results obtained through statistical analysis with software were compared with the data collected in the field, a comparison which resulted in an accuracy of approximately 95%. The results are reflected in table form and using maps also prepared with ArcGIS software.

Keywords: groundwater, river basin, RS, GIS, AHP.

INTRODUCTION

Groundwater is a very valuable natural resource and has become an extremely important and reliable source of water supply in urban and rural areas. According to Kumar et al 2006, human needs and economic development today generally depend on groundwater. Groundwater reserves are created by seeps of surface water and this phenomenon is infiltration.

Groundwater is a very important natural resource that is located on the earth's surface in the asthenosphere (Arulbalaji et al., 2019). Many researchers today think that approximately one-third of the world's population uses groundwater for water supply (Jose et al. 2012). Shakak 2015, thinks that the uncontrolled use of groundwater for irrigation purposes and water supply can also endanger groundwater resources.

The application of the geographical information system (GIS) has brought a very important approach in this field and the possibility to analyze many parameters (Mahato and Pal, 2019; Shailaja et al., 2019; Chen et al., 2019; Gueretz et al., 2019). Most of the research studies with GIS application were based on knowledge of factors analysis that uses different layers including drainage, elevation, geology, land use and land cover, lineament, rainfall, slope, and soil.

According to Shailaja et al., (2019) using remote sensing (RS) has benefited from combining primary and numeral data-set. A decisive role in the compilation and analysis of the synoptic scale is also played by the use of remote sensing (Mahato and Pal, 2019; Chen et al., 2019; Gueretz et al. 2019). The application of satellite RS techniques and image processing are mainly used in studies for preparing the needful layers for study. In addition to that, existing maps, databases, aerial photographs, and also data collection from the field are used for the preparation of these layers. The application of RS and GIS methods in different countries has been shown to be quite successful, giving very good results in determining the potential areas of underground water (Abel and Tijani, 2011; Bera and Bandyopadhyay, 2012; Deepika et al., 2013; Pandian and Kumanan, 2013; Gitas et al., 2014; Pinto et al., 2015).

Many researchers (Patra et al., 2018; Ferozu et al., 2018; Arefn, 2020; Bera et al., 2020; Mukherjee and Singh, 2020; Das and Mukhopadhyay 2020; Barua et al., 2021) have used these techniques to determine the potential of groundwater availability in a given region.

In order to determine and interpret suitable areas of groundwater, a combination of data was obtained from remote sensing and geographical information system software (Mahato et al., 2019; Qadir et al., 2019).

The researchers using those technics have prepared thematic factors such as geomorphology, geological formation, rainfall and soil types, surface runoff, land use, groundwater, and others (Pradhan et al., 2019; Rani et al., 2019; Maity et al., 2019.

STUDY AREA

The geographic position of the explored region

The study area is in the region of Ferizaj, which belongs to the southern part of Kosovo (Figure 1). The municipality of Ferizaj has a suitable geographical position for economic development, bordered in the east, by the municipality of Gjilan with a road distance of 32 km, and by the municipality of Vitia, with a road distance of 21 km from the center. In the south, it is bordered by the municipality of Kaçanik (16 km), in the southwest by Shtërpcë (32 km), in the west by Prizren (60 km) and Theranda (42 km), whereas in the north by Shtime (13 km) and Lipjani (17 km). The distance of Ferizaj from the capital of Kosovo, Pristina, is 36 km, and from Skopje 48 km. Air connections to Ferizaj are made through the airport of Pristina, which is 33 km away. The road distance between Ferizaj and Tirana is 350 km, while the distance to port of Durrësi is 384 km. The watershed of the Nerodime River covers a large area of around 217 km^2, with a width of 20 km and a length of 11 km. The central part is represented by the valley with an average altitude of 475 to 500 meters above sea level, while the side parts are characterized by mountains, with an altitude of up to 1700 meters.

Hydrographic features

The region of Ferizaj in the southwest is bordered by the mountain of Sharri, in the east by Karadak and Anamorava and in the northwest by the mountains of Drenica. The Nerodime River originates in the southern part of the Nerodime Mountain at an altitude of 1200 m and with a flow of 0.9 m^3/sec. The Nerodime River is an important tributary of the Lepenc River and together they flow into the Adriatic Sea. The Nerodime River has a small flow due to the bifurcation, an important geographical phenomenon that divides its waters into the Mediterranean and the Black Sea. The length of the Nerodime River is 29 km; the catchment area covers 255 km^2 (Figure 1).

METHODOLOGY

For the identification of potential groundwater areas in the Nerodime river catchment area, we have used various data including:

- digital elevation model (DEM) from Ministry of Environmental, Spatial Planning, and Infrastructure;
- LULC from 2022 Esri, Microsoft;
- soil data from Ministry of Environmental and Spatial Panning;
- rainfall data from Hydrometeorological Institute;
- geological and hydrogeological data from Independent Commission for Mines and Minerals.

The identification of potential groundwater zones has been carried out in a step-by-step order as displayed in the flowchart. The preparation of different layers and weighted overlay analysis has been done with the help of ArcGIS. Groundwater research would not be possible without the use of various data that have a direct impact on groundwater such as: geology, land use and land cover, soil, lineament, slope, elevation, rainfall, and drainage. These parameters have been selected based on their influence on the selection of water storage sites.

ArcGIS software is used to delineate watershed boundaries and calculate parameters used for modeling. Processing MODFLOW is used to prepare to model the watershed and PMPATH is used to run the model and to calculate the water balance (Figure 2).

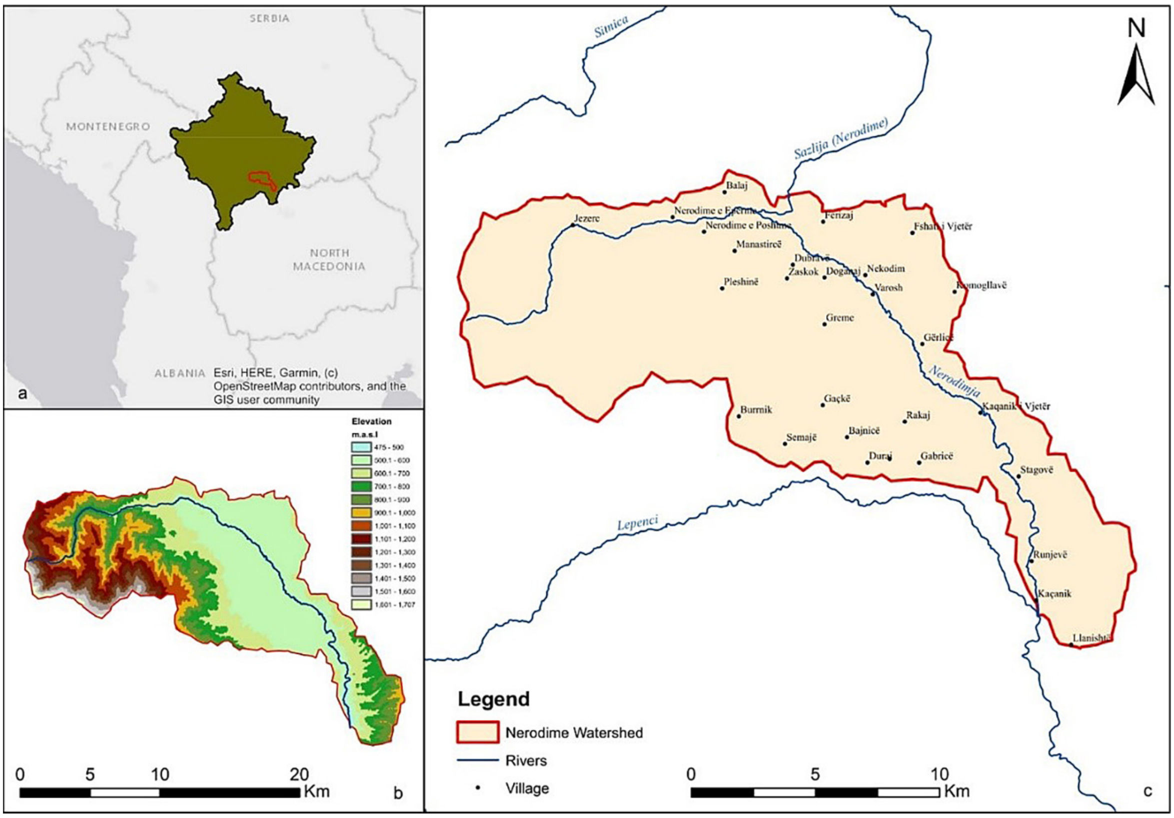

Figure 1. (a) Location of the study area, (b) geomorphological map, (c) map of the location of rivers, and villages

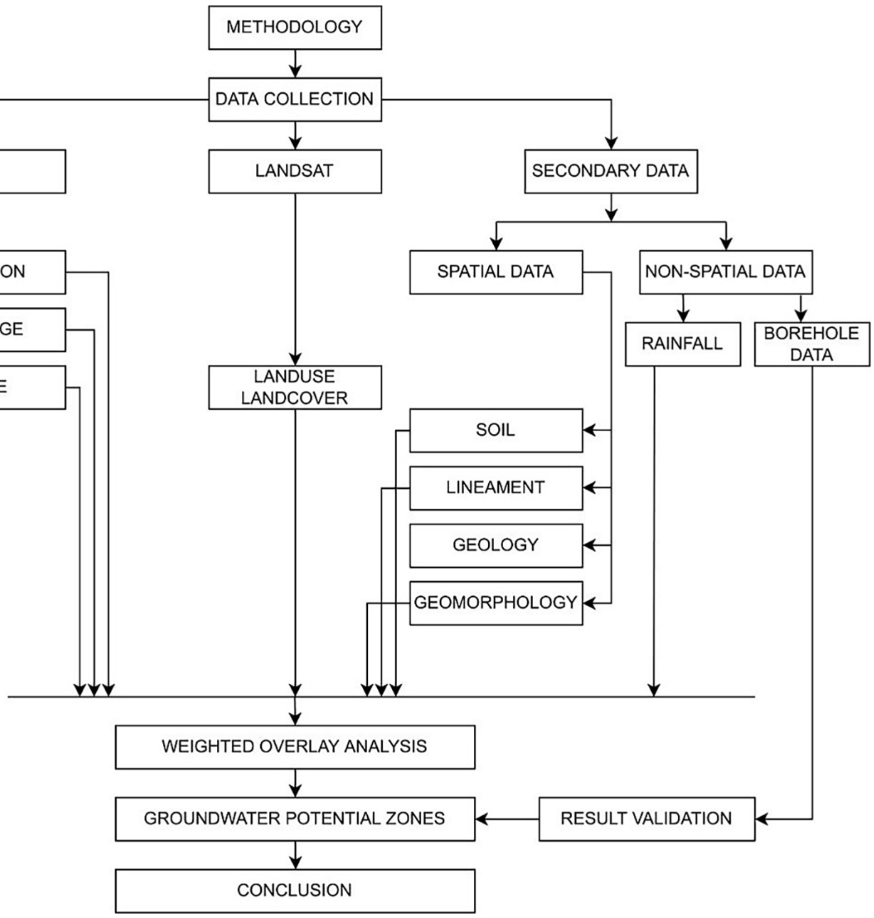

Figure 2. Methodology for the study

RESULTS AND DISCUSSION

A total of eight parameters are analyzed, which are listed below for description, each according to their importance and according to Satty's hierarchical analytical process. For each parameter, the textual description is made, as well as the maps planned for work are attached.

Drainage density

Drainage density is one of the main parameters used to identify potential groundwater areas. For the identification of potential groundwater zones, the drainage density method is one of the main parameters. If the drainage density is high, the water flow will also be higher, so water infiltration will be less. It should be noted that if the drainage density is high, the water flow will also be high, while the infiltration will be low. Whereas if the drainage density is low, the flow of water will also be low, while the infiltration will be high. For this study, the stream data was developed from the Aster DEM and these data were compared with the stream data collected by the Kosovo Geological Survey.

Spatial analyst tools were used to calculate drainage density, flow direction, accumulation, stream order and feature, and line density. In our case, as can be seen from the map, we have categorized the drainage density into 5 classes from the highest with a value of 3.95 to the lowest with a value of 0.57.

Elevation

As is known from current practices, water tends to be stored in low topographies and much less in

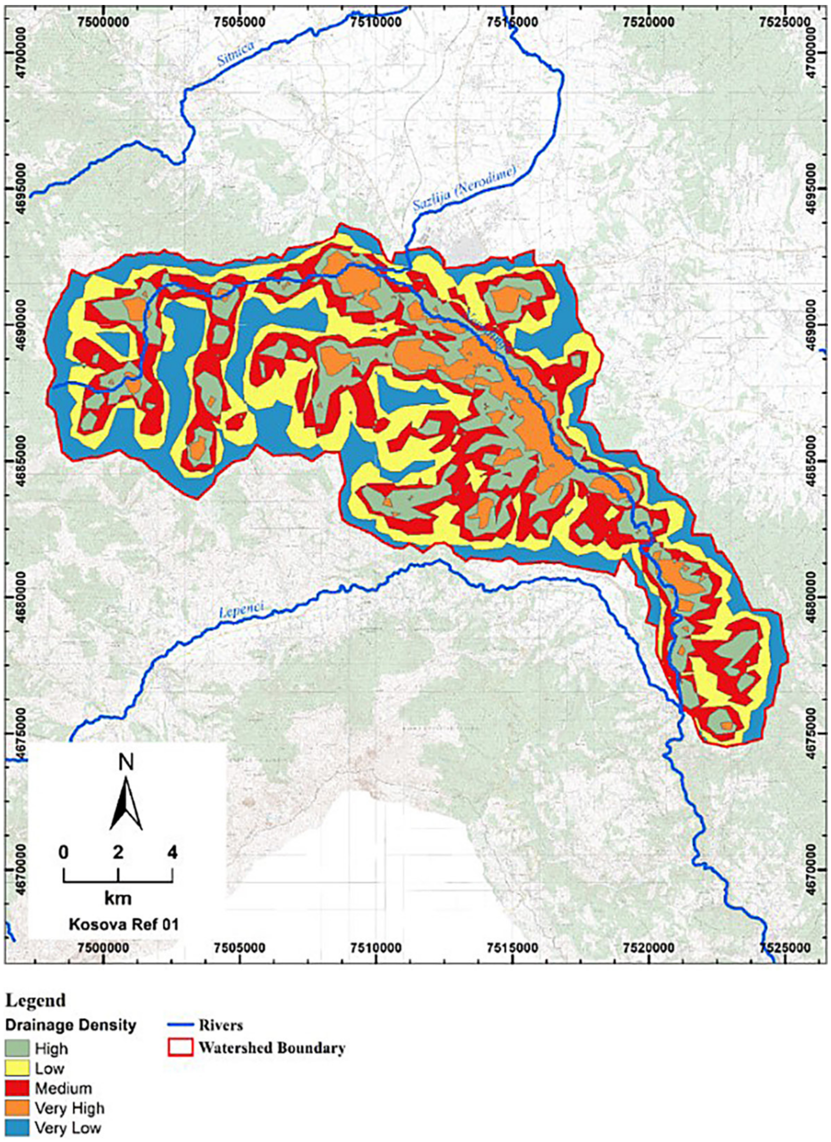

Figure 3. Drainage data of river basin

high topographies. Where we have low topography, the tendencies are higher for the presence of groundwater. The digital elevation model data with a spatial resolution of 30 meters were used. As seen in the map below, the height of the study area varies from 472 meters to over 1300 meters, where these values are classified into 5 different classes and the weight for each class is assigned.

Geology

Geology is recognized as a major factor that has a significant role in the distribution and occurrence of groundwater. The porosity of the rocks serves for the storage of water, where the higher the porosity, the more we have the presence of groundwater. In the study area, loam formations dominate mainly in the central part, surrounded by compact formations in the side parts, as shown in the following map. Their weight is determined depending on the lithology (Figure 5).

Land use and land cover (LU/LC)

As a result of population growth and great demands on land use, the land surface in some areas has been modified in recent years. Mainly where we have surfaces covered with vegetation, such as forests and vegetation, they block and hold water in their roots, as far as the use of land for construction and the rocky part affect the recharge of groundwater, because it increases the flow of water while it prevents infiltration. Landsat 8 satellite image was used to acquire land use images in the study area. The study area is covered by 6 different classes as they are bare ground, built

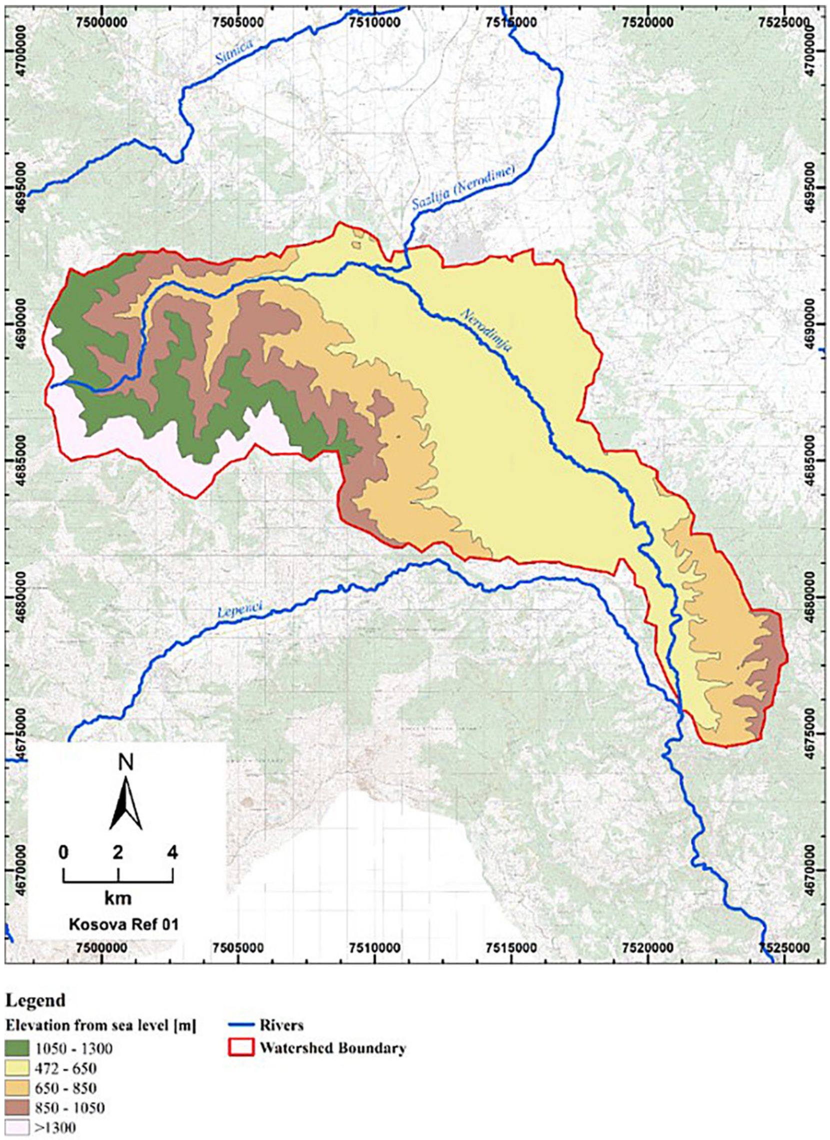

Figure 4. Elevation data of river basin

area, crops, scrub, trees, and water. The map was prepared using data from 2017–2021 (Figure 6).

Lineaments

Lineaments are a very important parameter that helps in the assessment of possible groundwater areas. Usually, linear structures (faults, cracks, etc.) affect the recharge of underground aquifers. The greater the density of linear structures in the watershed, the greater the possibility of groundwater recharge. In our case study, the lineaments are categorized into three groups using the buffer method with a distance of 0–250 m, 250–500 m, and over 500 m (Figure 7).

Rainfall

Rainfall is one of the major sources of groundwater availability through the hydrological cycle. The amount of rainfall is not the same in all locations and is different based on the environmental conditions of the place. Where the amount of rainfall is high, the possibility of groundwater is high, while where we have little rainfall, the possibility of groundwater is low. Rainfall not only changes in time and space but also changes in intervals, in this way to determine the impact of rainfall in each region, a long-term study is necessary.

For modeling in this study were used the rainfall data from 2010 to 2022. The data were

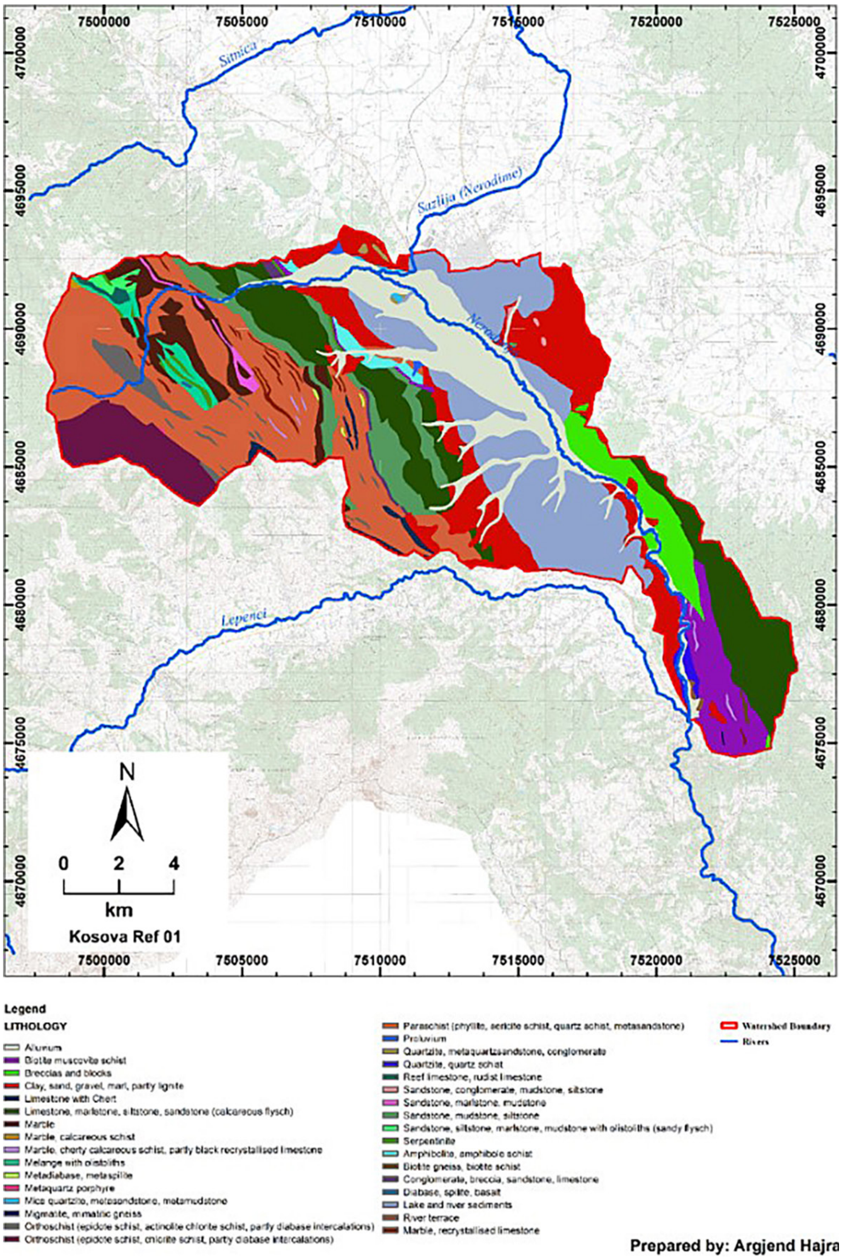

Figure 5. Geology data of river basin

obtained from the Hydrometeorological Institute of Kosovo, based on which the rainfall isohyets were built, which were classified into 5 areas, then the appropriate weight was determined for each class (Figure 8).

Slope

The slope plays a significant role in identifying groundwater recharge in the catchment area. This has an impact on runoff velocity, runoff retention on the soil surface, and infiltration capacity. Locations that are flat areas are hugely convenient for groundwater recharge as in these locations there is a high rate of infiltration and less surface runoff. Raised sections where the slope is high allowed for faster runoff and reduced infiltration of surface water into the soil. The slope of the study area was calculated using the DEM model, as well as running the Spatial Analysis Tools. The slope is classified into 5 classes and each class weight is assigned (Figure 9).

Soil

Soil is one of the main factors which determines the amount of groundwater in the study zone. Studying the soil of an area would help a lot to determine the types and properties of soil.

The soil porosity is important for many reasons. Knowing that soils contain high porosity, then the presence of groundwater in these environments cannot be avoided. Therefore, the study of soil is significant for determining the amount of groundwater in specific zones. The base data for the soil classification for this

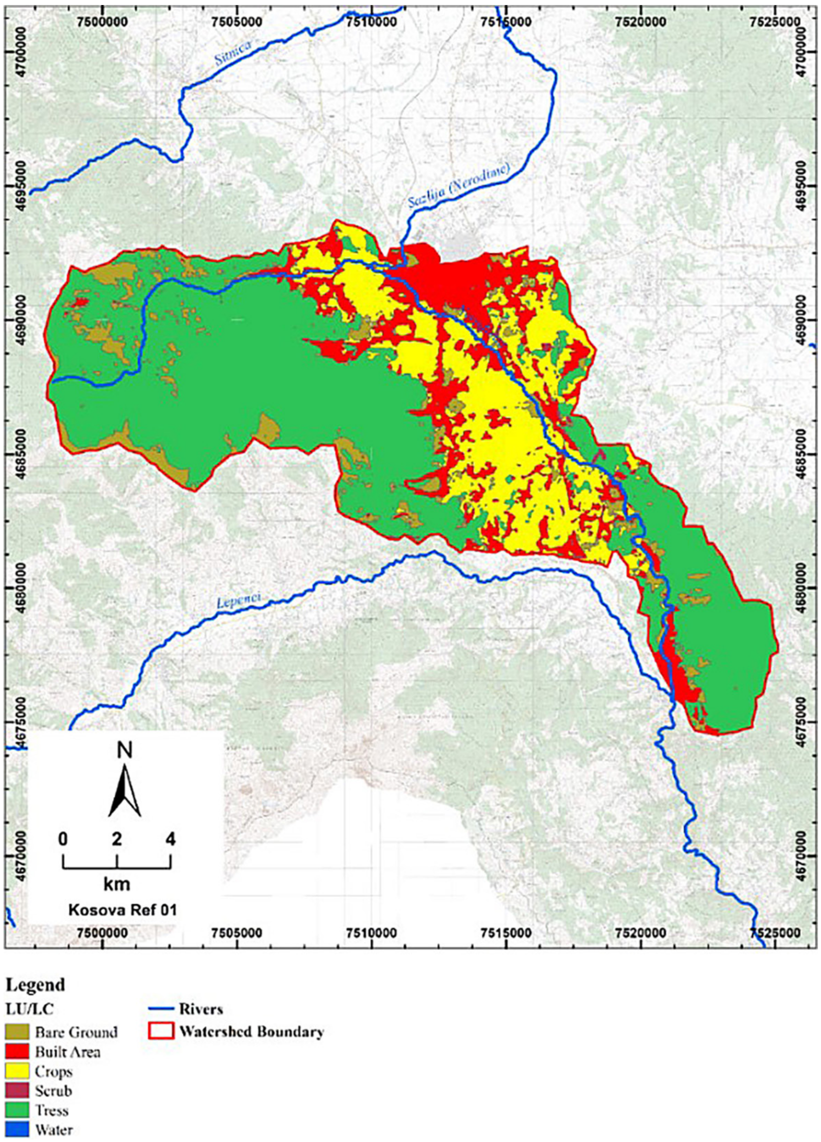

Figure 6. Land use and Land cover data of river basin

present study has been obtained from the Geological Service of Kosovo. Based on the data that we have available, can conclude that in the study area, there are different types of soils, such as red land, rendzina soil, deluvial and alluvial land. Since we are dealing with different types of soils in the research area, then the flow and penetration of water are different, in different areas, as well as the weight is determined based on their properties (Figure 10).

SATTY'S ANALYTICAL HIERARCHICAL PROCESS

Founded by Saaty in 1980, and is a popular and generally used method for multi-criteria decision-making. This method allows the use of qualitative, as well as quantitative criteria in evaluation. Develop and hierarchy of decision criteria and define the alternative courses of action. The analytic hierarchy process (AHP) algorithm is basically composed of two steps:

1. Determine the relative weights of the decision criteria.
2. Determine the relative rankings (priorities) of alternatives.

To make the best decision, the hierarchical analytical process considers several evaluation criteria and several alternative options. The evaluation procedure of the hierarchical analytical process is done by weighting the criteria according to pairwise comparisons of the decision maker's criteria. The most important criterion is the one with the highest weight. Then,

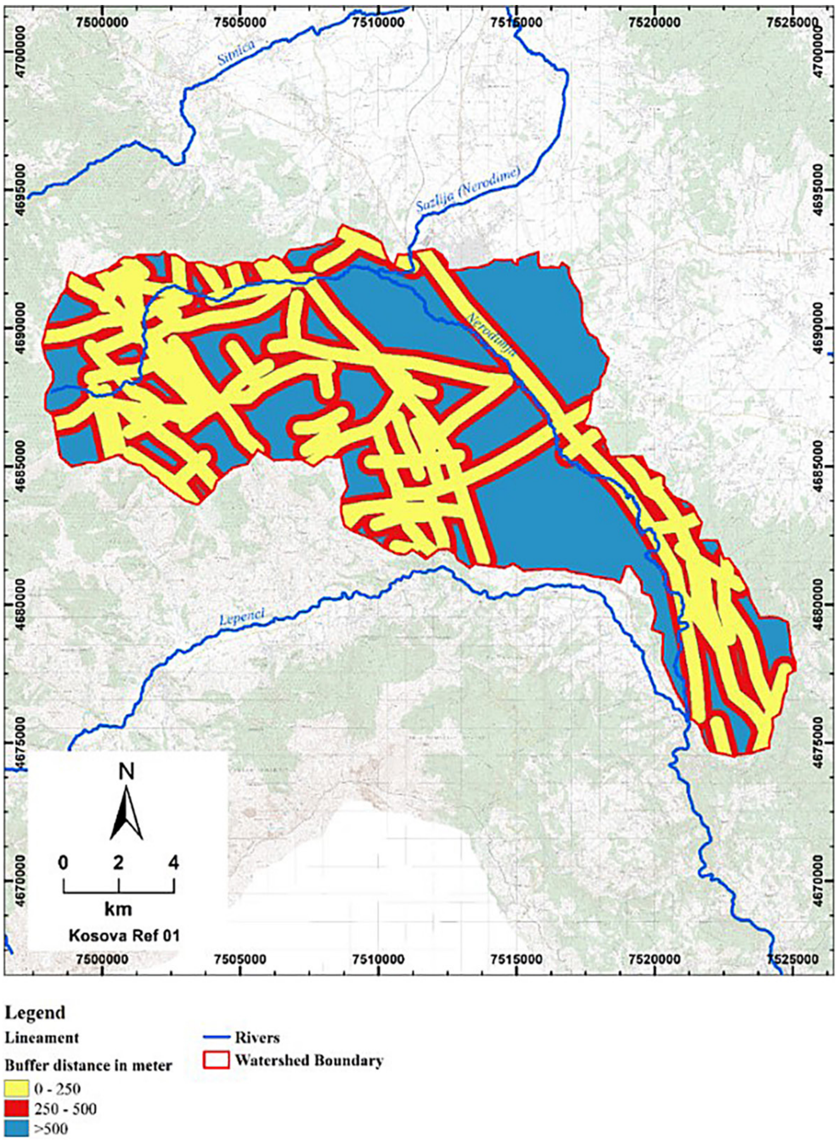

Figure 7. Lineament data of river basin

for a fixed criterion, AHP assigns a score to each option according to the pairwise comparison of the decision maker's options based on that criterion. In this way, the higher the score, the better the option's performance in relation to the considered criterion.

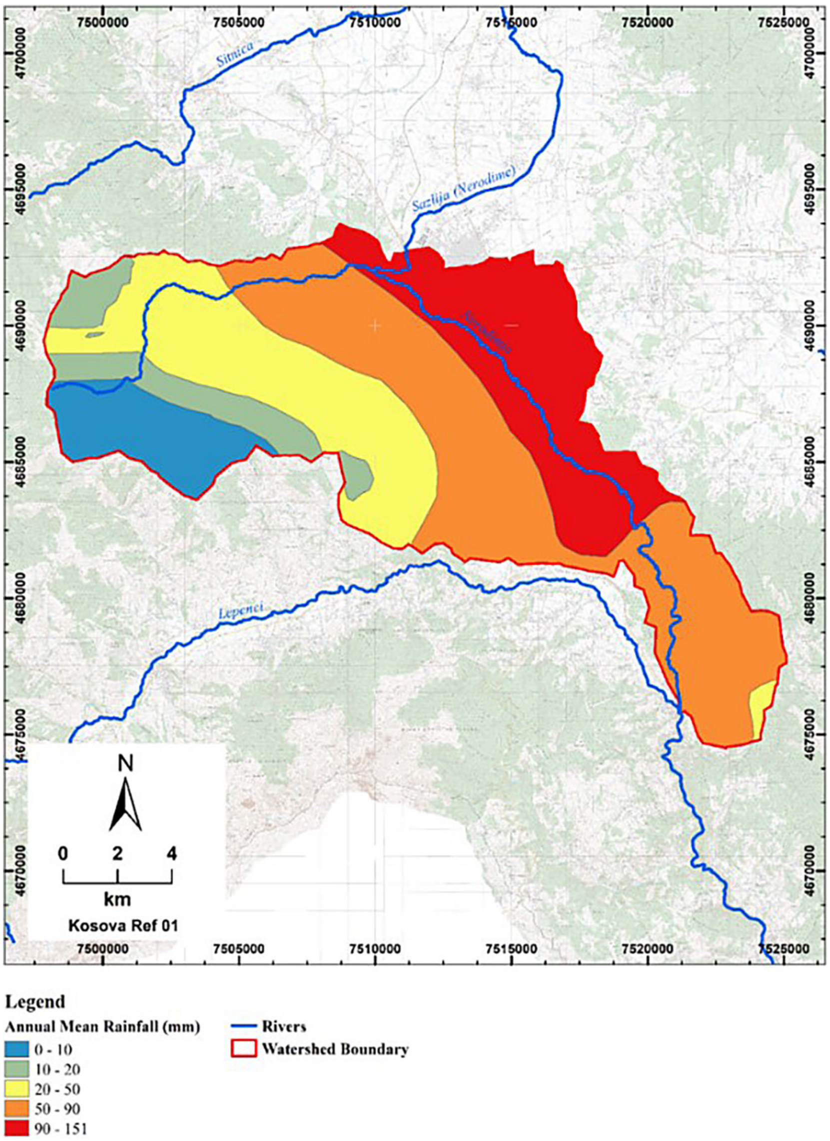

Figure 8. Rainfall data of river basin

Table 1. Influencing factor based on Satty's analytical hierarchical

No	Influencing factor	Value	Sattys scale (in Frac.)	Sattys scale (in Deci.)	% Influence = (Satty scale / Sum)*100	Relative influence value
1	Geology	High	1	1.00	36.79	37
2	Lineament	↓	1/2	0.50	18.40	18
3	Drainage density		1/3	0.33	12.26	12
4	Soil		1/4	0.25	9.20	9
5	Slope		1/5	0.20	7.36	7
6	Rainfall		1/6	0.17	6.13	6
7	Land use/Land cove		1/7	0.14	5.26	5
8	Elevation	Low	1/8	0.13	4.60	5
Sum				2.72		

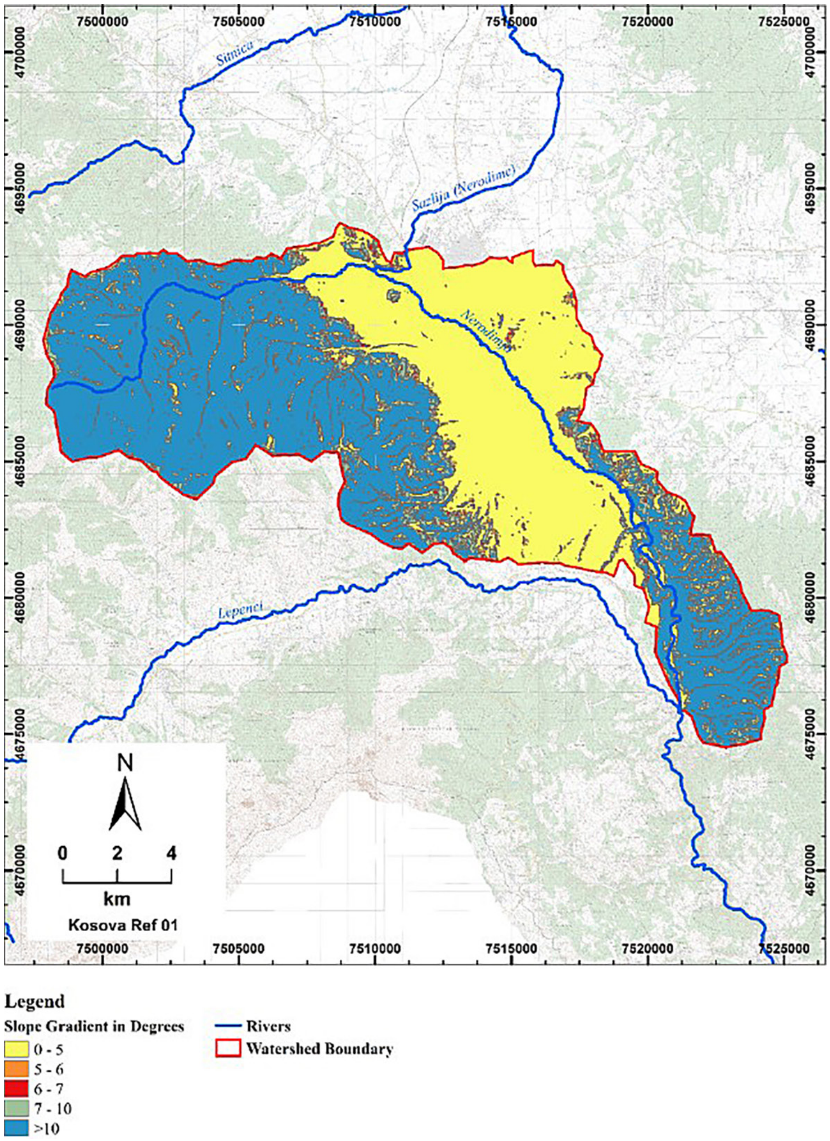

Figure 9. Slope data of river basin

Weighted overlay

After the weightage of each main parameter has been determined (Table 1), the weightage for the sub-class of main parameters has been assigned as mentioned in Table 2. Then the tool 'Weighted Overlay' in the Overlay Toolset which is built inside of Spatial Analyst Tools in ArcGIS has been used to perform an overlay analysis. The results are obtained when the weighted overlay tool overlays several rasters, based on which it uses a common measurement scale and weights each one according to its importance. Classification into five classes such as very low, low, medium, high, and very high, is made from the obtained results (Figure 11). From the result of the classification, it has been found that 60.6 km^2 of areas are having very high potential groundwater; 0.75 km^2 of areas are having high, 53 km^2 have moderate, 55.1 km^2 have low and 48.6 km^2 areas are having very low potential groundwater. The results of the study also display that a central part of the Nerodime watershed has more available groundwater than other areas.

CONCLUSIONS

The application of GIS, RS, and AHP techniques is good and very cost-effective and at the same time very effective in determining the potential areas of underground water in the study location. The present study that uses ArcGIS 10.5 software tools for the identification of areas with groundwater shows us that a wide area has been covered with a high presence of groundwater,

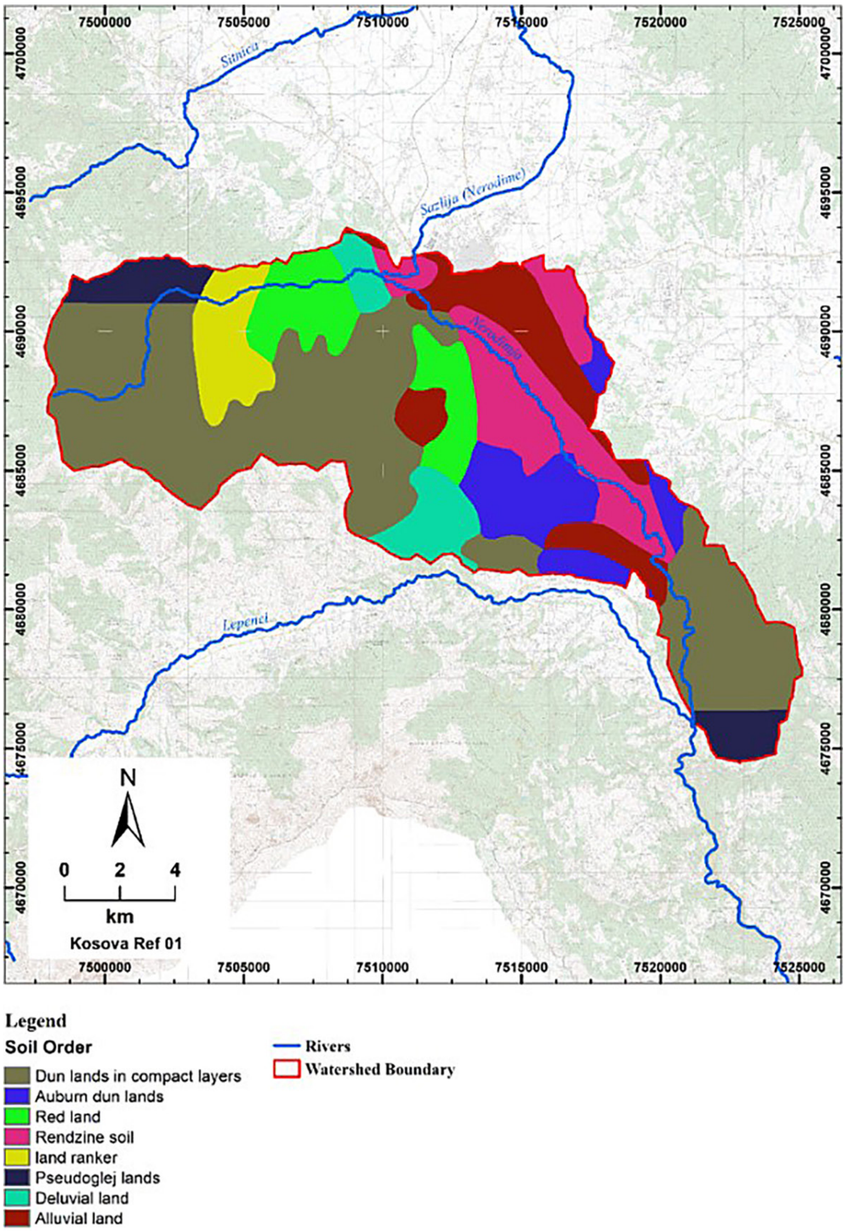

Figure 10. Soil order data of river basin

Table 2. Weight according to Satty's analytical hierarchical

Influencing factor	Class interval	Groundwater availability	Sattys scale in decimal	% Weight = (Sattys scale/sum)*100
Drainage Density	2.43–3.95	Very high	1.000	43.7956
	1.79–2.43	High	0.500	21.8978
	1.21–1.79	Medium	0.333	14.5985
	0.57–1.21	Low	0.250	10.9489
	0–0.57	Very low	0.200	8.7591
	Sum		2.283	
Elevation	472–650	Very high	1.000	43.7956
	650–850	High	0.500	21.8978
	850–1050	Medium	0.333	14.5985
	1050–1300	Low	0.250	10.9489
	>1300	Very low	0.200	8.7591
	Sum		2.283	

Table 2. Cont. Weight according to Satty's analytical hierarchical

Influencing factor	Class interval	Groundwater availability	Sattys scale in decimal	% Weight = (Sattys scale/sum)*100
Geology	Alluvium	Very high	1.000	10.1180
	Biotite muscovite schist	Very low	0.200	2.0236
	Breccias and blocks	Very low	0.200	2.0236
	Clay, sand, gravel, marl, partly lignite	Very high	1.000	10.1180
	Limestone with Chert	Low	0.250	2.5295
	Limestone, marlstone, siltstone, sandstone (calcareous flysch)	Low	0.250	2.5295
	Marble	Very low	0.200	2.0236
	Marble, calcareous schist	Very low	0.200	2.0236
	Marble, cherty calcareous schist, partly black recrystallised limestone	Very low	0.200	2.0236
	Melange with olistoliths	Low	0.250	2.5295
	Metadiabase, metaspilite	Very low	0.200	2.0236
	Metaquartz porphyre	Very low	0.200	2.0236
	Mica quartzite, metasandstone, metamudstone	Very low	0.200	2.0236
	Migmatite, mimatitic gneiss	Very low	0.200	2.0236
	Orthoschist (epidote schist, actinolite chlorite schist, partly diabase intercalations)	Very low	0.200	2.0236
	Orthoschist (epidote schist, chlorite schist, partly diabase intercalations)	Very low	0.200	2.0236
	Paraschist (phyllite, sericite schist, quartz schist, metasandstone)	Very low	0.200	2.0236
	Proluvium	Medium	0.333	3.3727
	Quartzite, metaquartzsandstone, conglomerate	Very low	0.200	2.0236
	Quartzite, quartz schist	Very low	0.200	2.0236
	Reef limestone, rudist limestone	Low	0.250	2.5295
	Sandstone, conglomerate, mudstone, siltstone	Low	0.250	2.5295
	Sandstone, marlstone, mudstone	Low	0.250	2.5295
	Sandstone, mudstone, siltstone	Low	0.250	2.5295
	Sandstone, siltstone, marlstone, mudstone with olistoliths (sandy flysch)	Low	0.250	2.5295
	Serpentine	Very low	0.200	2.0236
	Amphibolite, amphibole schist	Very low	0.200	2.0236
	Biotite gneiss, biotite schist	Very low	0.200	2.0236
	Conglomerate, breccia, sandstone, limestone	Low	0.250	2.5295
	Diabase, spilite, basalt	Very low	0.200	2.0236
	Lake and river sediments	High	0.500	5.0590
	River terrace	Very high	1.000	10.1180
	Marble, recrystallized limestone	Very low	0.200	2.0236
	Sum		9.883	
LU/LC	Tress	Very high	1.000	39.4737
	Crops	High	0.500	19.7368
	Water	Medium	0.333	13.1579
	Built Area	Low	0.250	9.8684
	Bare Ground	Low	0.250	9.8684
	Scrub	Very low	0.200	7.8947
	Sum		2.533	

Table 2. Cont. Weight according to Satty's analytical hierarchical

Influencing factor	Class interval	Groundwater availability	Sattys scale in decimal	% Weight = (Sattys scale/sum)*100
Lineament	0–250	High	1.000	65.2174
	250–500	Medium	0.333	21.7391
	>500	Low	0.200	13.0435
	Sum		1.533	
Rainfall	90–151	Very high	1.000	43.7956
	50–90	High	0.500	21.8978
	20–50	Medium	0.333	14.5985
	10–20	Low	0.250	10.9489
	0–10	Very low	0.200	8.7591
	Sum		2.283	
Slope	0–5	Very high	1.000	43.7956
	5–6	High	0.500	21.8978
	6–7	Medium	0.333	14.5985
	7–10	Low	0.250	10.9489
	>10	Very low	0.200	8.7591
	Sum		2.283	

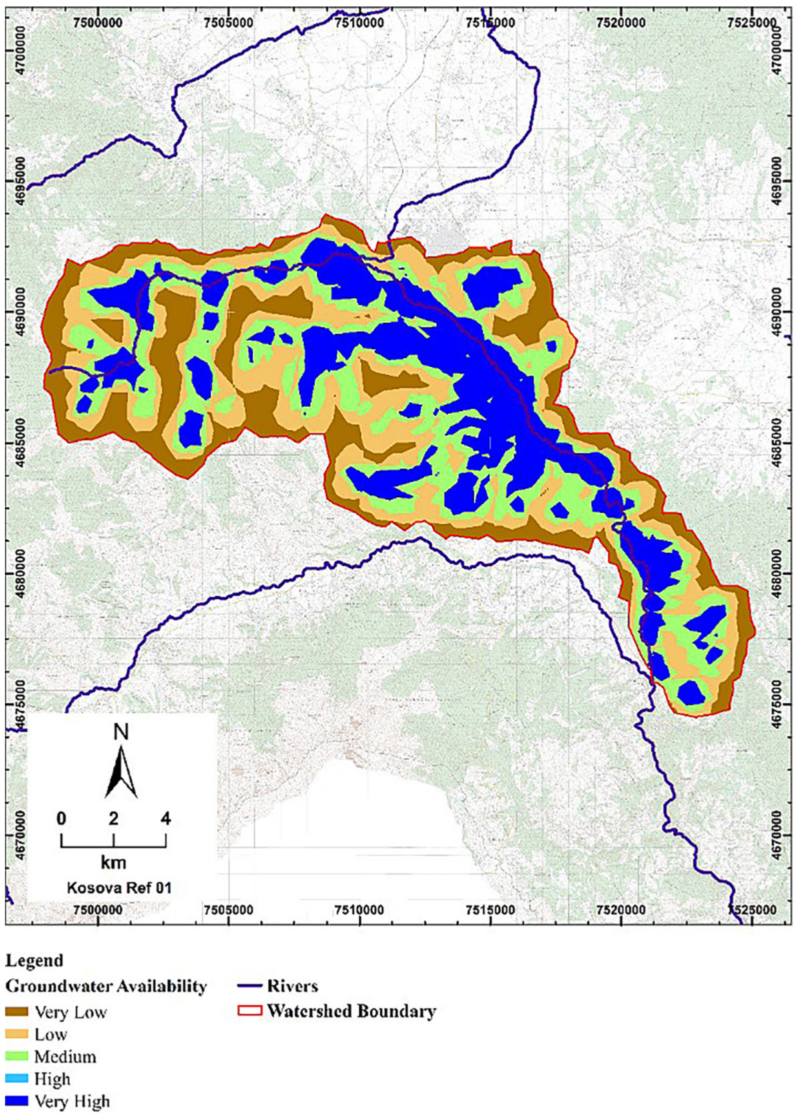

Figure 11. Groundwater potential zones of Watershed Nerodime

followed by areas with low potential, medium potential, and areas with very low potential covered a smaller area. As can be seen from the results of the study, the integration of eight parameters provides sufficient information for determining and identifying areas with groundwater potential. Particular importance has been given to precipitation and water flows, considering them as the major source of groundwater recharge. To prove the current result, data on the sources of groundwater in this catchment were collected in the field. Field data as well as modeling results according to Satty's are very approximate. Therefore, based on the obtained results and precision, the study suggests that this method would be adequate for the research of potential groundwater areas. The accuracy of the study result with the sample data proves that Satty's Hierarchical Analytical Process is one of the suitable weighting methods for groundwater studies. The study also recommends the use of GIS technology with RS data for further groundwater surveys, which can reduce cost, time, and manpower with higher accuracy.

REFERENCES

1. Abel O.T., Tijani M. 2011. Integrated remote sensing and GIS approach to groundwater potential assessment in the basement terrain of Ekiti area southwestern Nigeria. Mater Geoenviron, 58(3), 303–328.
2. Arefn R. 2020. Groundwater potential zone identifcation using an analytic hierarchy process in Dhaka City, Bangladesh. Environ Earth Sci. https://doi.org/10.1007/s12665-020-09024-0
3. Arulbalaji P., Padmalal D., Sreelash K. 2019. GIS and AHP techniques based delineation of groundwater potential zones: a case study from Southern Western Ghats India. Sci Rep. https://doi.org/10.1038/s41598-019-38567-x
4. Barua S., Mukhopadhyay B.P., Bera A. 2021. Integrated assessment of groundwater potential zone under agricultural dominated areas in the western part of Dakshin Dinajpur district, West Bengal, India. Arab J Geosci, 14, 1042. https://doi.org/10.1007/s12517-021-07312-y
5. Bera A., Mukhopadhyay B.P., Barua S. 2020. Delineation of groundwater potential zones in Karha river basin, Maharashtra, India, using AHP and geospatial techniques. Arab J Geosci, 13, 693. https://doi.org/10.1007/s12517-020-05702-2
6. Bera K., Bandyopadhyay J. 2012. Groundwater potential mapping in Dulung watershed using remote sensing and GIS techniques, West Bengal, India. Int J Sci Res Publ, 2(12), 1–7.
7. Chen W., Hong H., Li S., Shahabi H., Wang Y., Wang X., Ahmad B.B. 2019. Flood susceptibility modelling using novel hybrid approach of reduced-error pruning trees with bagging and random subspace ensembles. J Hydrol, 575, 864–873. https://doi.org/10.1016/j.jhydrol.2019.05.089
8. Das N., Mukhopadhyay S. 2020. Application of multi-criteria decision making technique for the assessment of groundwater potential zones: a study on Birbhum district, West Bengal, India. Environ Dev Sustain, 22, 931–955. https://doi.org/10.1007/s10668-018-0227-7
9. Deepika B., Avinash K., Jayappa K.S. 2013. Integration of hydrological factors and demarcation of groundwater prospect zones: insights from remote sensing and GIS techniques. Environ Earth Sci, 70(3), 1319–1338. https://doi.org/10.1007/s12665-013-2218-1
10. Ferozu R.M., Jahan C.S., Arefn R., Mazumder Q.H. 2018. Groundwater potentiality study in drought prone Barind Tract, NW Bangladesh using remote sensing and GIS. Groundw Sustain Dev, 8, 205–215. https://doi.org/10.1016/j.gsd.2018.11.006
11. Gitas I.Z., Ayanz J.S.M., Chuvieco B.D.E., Camia A. 2014. Advances in remote sensing and GIS applications in support of forest fire management. Int J Wildland Fire, 23, 603–605. https://doi.org/10.1071/WF14117
12. Gueretz J.S., Da Silva F.A., Simionatto E.L., Ferard J.F., Radetski C.M., Somensi C.A. 2019. A multiparametric study of the interaction between the Parati river and Babitonga Bay in terms of water quality. J Environ Sci Health, Part B. https://doi.org/10.1080/03601234.2019.1685813
13. Jose S.K., Jayasree R., Kumar R.S., Rajendran S. 2012. Identification of Ground Water Potential Zones in Palakkad District, Kerala Through Multicriteria Analysis Techniques using Geoinformation Technology, 2(1), 62–68
14. Kumar P., Herath S., Avtar R., Takeuchi K. 2016. Mapping of groundwater potential zones in Killinochi area, Sri Lanka, using GIS and remote sensing techniques. Sustain. Water Resour. Manag., 2(4), 419–430. https://doi.org/10.1007/s40899-016-0072-5
15. Mahato S., Pal S. 2019. Groundwater potential mapping in a rural river basin by union (OR) and intersection (AND) of four multi-criteria decision-making models. Nat Resour Res, 28(2), 523–545. https://doi.org/10.1007/s11053-018-9404-5
16. Maity D.K., Mandal S. 2019. Identification of groundwater potential zones of the Kumari river basin, India: an RS & GIS based semi quantitative approach. Environ Dev Sustain, 21(2), 1013–1034. https://doi.org/10.1007/s10668-017-0072-0

17. Mukherjee I., Singh U.K. 2020. Delineation of groundwater potential zones in a drought-prone semi-arid region of east India using GIS and analytical hierarchical process techniques. CATENA, 194, 104681. https://doi.org/10.1016/j.catena.2020.104681
18. Pandian M., Kumanan C.J. 2013. Geomatics approach to demarcate groundwater potential zones using remote sensing and GIS techniques in part of Trichy and Karur district, Tamilnadu, India. Appl Water Sci, 5(2), 234–240.
19. Patra S., Mishra P., Mahapatra S.C. 2018. Delineation of groundwater potential zone for sustainable development: a case study from Ganga Alluvial Plain covering Hooghly district of India using remote sensing, geographic information system and analytic hierarchy process. J Clean Prod, 172, 2485–2502. https://doi.org/10.1016/j.jclepro.2017.11.161
20. Pinto D., Shrestha S., Babel M.S., Ninsawat S. 2015. Delineation of groundwater potential zones in the Comoro watershed, Timor Leste using GIS, remote sensing and analytic hierarchy process (AHP) technique. Appl Water Sci. https://doi.org/10.1007/s13201-015-0270-6
21. Pradhan S., Kumar S., Kumar Y., Sharma H.C. 2019. Assessment of groundwater utilization status and prediction of water table depth using different heuristic models in an Indian interbasin. Soft Comput, 23(20), 10261–10285. https://doi.org/10.1007/s00500-018-3580-4
22. Qadir J., Bhat M.S., Alam A., Rashid I. 2019. Mapping groundwater potential zones using remote sensing and GIS approach in Jammu Himalaya Jammu and Kashmir. Geo-Journal, 85(2), 487–504. https://doi.org/10.1007/s10708-019-09981-5
23. Rani M., Joshi H., Kumar K., Pande A., Rawat D.S. 2019. Development of recharge and conservation site suitability model for groundwater retrieval and evaluation of artificial recharge potential in a complex hydro-geological spring-fed river basin. Arab J Geosci, 12(18), 589. https://doi.org/10.1007/s12517-019-4784-3
24. Shailaja G., Kadam A.K., Gupta G., Umrikar B.N., Pawar N.J. 2019. Integrated geophysical, geospatial and multiple-criteria decision analysis techniques for delineation of groundwater potential zones in a semi-arid hard-rock aquifer in Maharashtra India. Hydrogeol J, 27(2), 639–654. https://doi.org/10.1007/s10040-018-1883-2
25. Shakak N. 2015. Integrationof Remote Sensing and Geographic information system in Ground Water Quality Assessment and Management. ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XL-7/W3 (May), 1483–1490. https://doi.org/10.5194/isprsarchives-XL-7-W3-1483-2015