

Multi-criteria evaluation based groundwater potential zonation of Pampore watershed using geo-spatial tools

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ABSTRACT

Groundwater is a sub-surface phenomenon. However, there are a number of surface features which could be used as evidences of groundwater potential and occurrence. Remote sensing and GIS techniques have emerged as very effective and reliable tools in the assessment, monitoring and conservation of groundwater resources. A total of nine groundwater contributing factors were analyzed in a GIS environment to delineate the Groundwater potential (GWP) zones in Pampore watershed based on multi-criteria evaluation approach. Appropriate knowledge-based weights and ranks were assigned to these factors based on their impact on groundwater occurrence. These ranks and weights were normalized in order to remove the biasness of scale. Slope was assigned the highest weight of while altitude was assigned the lowest weight. All the thematic layers were superimposed by weighted overlay method using GIS for generating GWP map. The study area was divided into four GWP zones of high, moderate, low and very low potential covering an area of (15.404%), (33.402%), (39.161%), and (12.030%) respectively. The study revealed that the area is dominated by low GWP zone followed by medium, high and very low GWP. The study area is the most important saffron producing belt of Kashmir and the results of this study could be utilized for devising sustainable irrigation policy for the study area.

Keywords: Groundwater; Multi-criteria; Remote sensing; GIS; Pampore.

INTRODUCTION

Groundwater is one of the very precious natural resource on earth and is primary source of life that sustains all human activities. It is essentially required not only for the sustenance of the human life but also for the economic and social progress of a region. It constitutes a major portion of the earth's water circulatory system known as "hydrologic system". Although it is more dynamic renewable natural resource yet its availability with good quality and quantity in appropriate time and space is more important (Chaudhary et al., 1996). Due to increasing population, urbanization, deforestation and industrialization, pressure on this resource is continuously increasing. Hence, delineation of GWP zones has acquired greater importance.

A large portion of the world's irrigated agriculture as well as industries are dependent on ground water. As a result of growth in global population, the demand for clean water is rising and the pressure on surface and groundwater resource is increasing, particularly in semi-arid and arid regions of the world where usable water supplies are scarce. India is largest groundwater user in the world, with an estimated usage of around 230 km³ per year, more than a quarter of global groundwater. Groundwater is a vital resource for rural areas in India as more than 60 per cent of irrigated agriculture and 85 per cent of drinking water supplies are dependent on it (Clifton et al., 2010). Agricultural demand for irrigation is already the single largest draw on India's water, yet estimates by the Ministry of Water Resources indicate that by the year 2050 irrigation needs will rise by 56 per cent.

Advent of satellite remote sensing and GIS has opened new field of vision for groundwater studies. Remote sensing and GIS technology, with its advantages of spatial, spectral and temporal availability of data covering large and inaccessible areas within a short time (Hoffmann and Sander, 2007), has emerged as a very useful tool for the assessment, monitoring and management of groundwater resources (Jha et al., 2007). Remote sensing and GIS tools can be used to detect areas with high potential for groundwater exploration (Wahyuni et al., 2008; Deepika et al., 2013, Malik et al., 2016).

Groundwater is a subsurface phenomenon and it cannot be detected directly. However there are certain surface features which help to identify groundwater. The identification of groundwater sources using traditional methods is very tedious and costly. Besides, the recent advances in the science of Remote Sensing have made it possible to identify groundwater with a fair amount of accuracy using indirect evidences. A number of studies have been carried out to identify GWP zones using Remote Sensing by applying varied methodologies. These studies have used different set of indicators to identify GWP zones.

The difference in the selection of indicators is prominent because the applications of Remote Sensing and Geographic information system (GIS) in groundwater application are in its infancy stage.

Though the valley of Kashmir has abundant water resources but their spatial distribution is highly varied. The mountainous areas characterised by the abundance of glaciers are the source of perennial rivers which provide adequate water availability in the Jhelum River. However, rim lands and Karewa belt of Kashmir faces water shortage problems because of limited number of surface water streams. The Karewa belt, which is found to be dominant in the study area, is hence devoted to dry farming especially horticulture, maize and saffron cultivation. The agricultural activities in this region are entirely dependent on the availability of rainfall and groundwater resources. However, scanty rainfall in the recent decades has resulted into crop failures and consequent economic losses to the farmers. Farmers are shifting cultivation from saffron crop to apple crop because of lack of optimum irrigation facility required for the saffron crop thereby, resulting in the reduction of saffron area coverage. So, in order to combat with the water scarcity problems prevalent in saffron cultivated areas, the multi-criteria evaluation approach for GWP zoning in the Pampore watershed has been selected to augment the irrigation facility during dry periods. In this backdrop, the study aims to identify GWP zones so that the underground water is utilised properly to meet the water requirement of the saffron crop.

STUDY AREA

The study area is the Pampore watershed, which is situated between the geographical coordinates of 33.961° to 34.035° N latitude and 74.923° to 75.059 ° E longitudes lying in Pulwama district of Jammu & Kashmir, which is located in the central part of Kashmir Valley and is mostly dominated by agricultural occupation. The location map of the study area is shown in Fig.1. The watershed has an area of 16,391 hectares. Pampore is a historic town situated on the eastern side of river Jhelum on Srinagar-Jammu National Highway in Jammu and Kashmir. It is worldwide famous for its Saffron, so known as “Saffron Town of Kashmir”. Pampore is one of the few places in the world where saffron, the world’s most expensive spice, grows. Kashmir saffron is a high value, low volume crop and the quality of saffron is among the best in the world particularly because of its rich colour and flavour. A small area in the valley, Pampore has the virtual monopoly of saffron cultivation in the country.

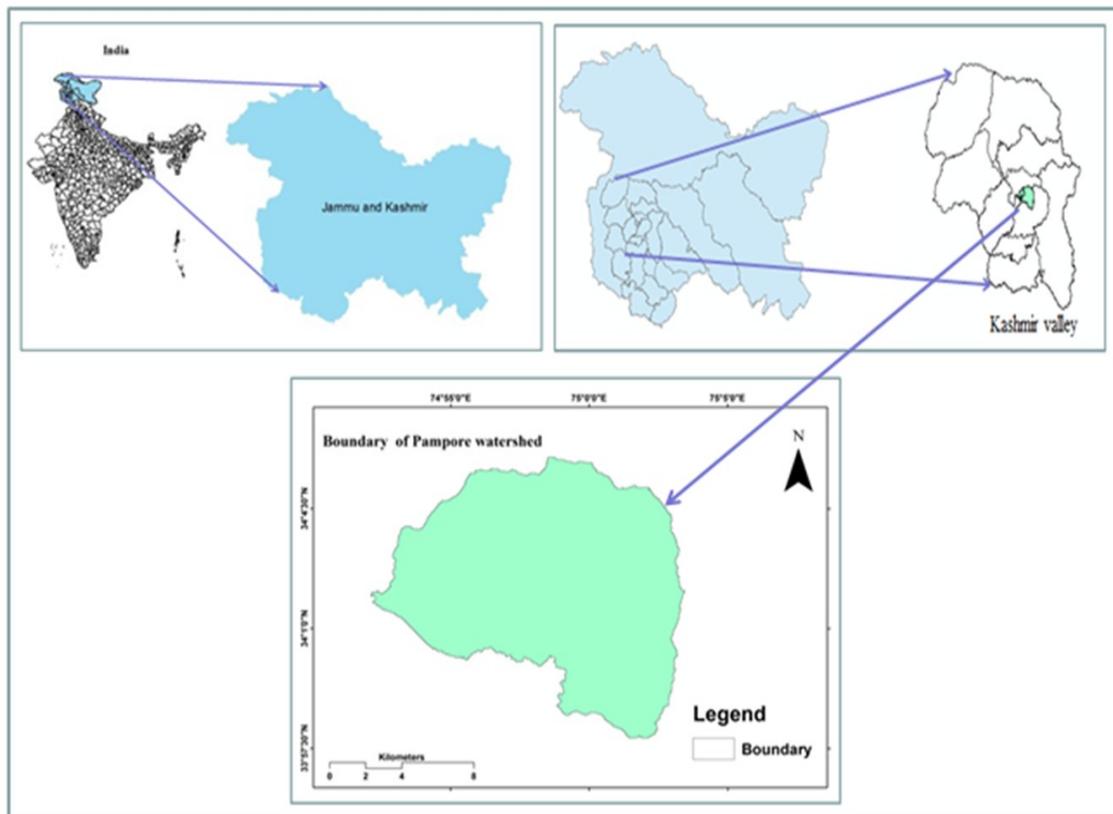


Fig. 1: Location map of Pampore watershed

MATERIALS AND METHODS**Data Sets Used**

The various parameters or datasets taken for identifying GWP zones include:

1. Survey of India Toposheets (Year 1961).
2. Digital Elevation Model (ASTER Dem with the resolution of 30 m)
3. LISS-IV Satellite data (NRSC Hyderabad).
4. Soil map (NBSS and LUP, Nagpur).
5. Geology map (Department of Geology and Mining, Srinagar).
6. Rainfall data (Meteorological department).

Methods Used

Generation of thematic layers: The slope and altitude maps were derived from the DEM by using surfacing module in spatial analyst tool provided in ARC Toolbox of Arc GIS 10.2 software. Average rainfall data of 10 years (2006-2016) of three stations namely Pahalgam, Qazigund and Srinagar was processed by using Krigging option available in geo-statistical wizard of ArcGIS 10.2 software in order to generate rainfall distribution map. Geology map was digitised from the existing geology map generated by the Department of Geology and Mining, Srinagar. Geomorphology map was prepared by field observation and visual interpretation of LISS IV satellite imagery of 5.8 m resolution. Soil map of study area was prepared from existing soil map of Kashmir valley prepared by National Bureau of Soil Science and Land use Planning of ICAR at the scale of 1:250,000. This map was validated by field and laboratory observations. LULC map was prepared from LISS-IV satellite imagery (5.8 m resolution) by using supervised digital classification technique. Lineament density map was prepared from LISS IV satellite imagery of 5.8m resolution by digitising linear and curvilinear features on satellite imagery by visual interpretation technique. Both major and minor lineaments in the study area were delineated which include faults, fracture, cracks, etc. Drainage map was digitized as a line coverage showing the entire stream network. The tributaries of different extents and patterns were digitized from the geo-referenced mosaic of toposheets and updated from satellite data (LISS IV). The drainage density of the watershed was calculated by Horton's method (Horton 1932).

$$D_d = \frac{L\mu}{A} \quad (1)$$

Where, D_d = Drainage density, $L\mu$ = Total stream length of all orders and A = Area of the basin (km^2).

Table 1: Weight and rank table of different indicators and their sub-categories

S. No.	Indicator			Sub-indicator		
	Category	Weight	Normalised weight (W)	Sub-category	Rank	Normalised Rank (r)
1	Slope (degree)	9	0.20	<10	10	0.37
				10-20	8	0.30
				20-30	6	0.22
				30-40	2	0.07
				> 40	1	0.04
2	Geology	8	0.18	Alluvium	5	0.33
				Karewas formation	4	0.27
				Triassic limestone	3	0.20
				Zewan formation	2	0.13
				Panjal trap	1	0.07
3	Rainfall	7	0.16	<900	1	0.10
				900-950	2	0.20
				950-1000	3	0.30
				>1000	4	0.40
4	Drainage Density (km/km^2)	6	0.13	< 1	5	0.33
				1.0-2.0	4	0.27
				2.0-3.0	3	0.20
				3.0-4.0	2	0.13
				> 4.0	1	0.07
5	Land use land cover (LULC)	5	0.11	Water body; Wetland	8	0.24
				Closed forests; Mixed plantation	7	0.21

				Agriculture field; Vegetable field; Orchard and horticulture	6	0.18
				Open forests; Saffron- horticulture (dual crops)	5	0.15
				Saffron field;	4	0.12
				Meadows; Scrub land	2	0.06
				Built-up; Barren land	1	0.03
6	Lineament density (km/km ²)	4	0.04	<1.5	1	0.06
				1.5-2.5	3	0.19
				2.5-3.5	5	0.31
				>3.5	7	0.44
7	Soil	3	0.07	Sandy loam	3	0.50
				Silty loam	2	0.33
				Clayey loam	1	0.17
8	Geomorphology	2	0.04	Flood plain	4	0.40
				Karewa land	3	0.30
				Valleys	2	0.20
				Mountains	1	0.10
9	Altitude	1	0.16	<2000	4	0.40
				2000-2500	3	0.30
				2500-3000	2	0.20
				>3000	1	0.10

Source: Adopted from Jha et al., 2010, Deepika et al., 2013; Machiwal et al., 2014 and Malik et al., 2016

Mapping of GWP zones: A weighted linear combination technique of Multi-Criteria Evaluation (MCE) was adopted to calculate the GWP index. The MCE is based on previous works of Jha et al. (2010), Machiwal et al. (2011), Deepika et al. (2013) and Malik et al., (2016). Knowledge-based weights and ranks were assigned to indicators and their sub-categories. Weights were given to all the nine indicators and their sub-categories (table 1) on the basis of their contribution towards groundwater occurrence. The maximum value was given to the feature with highest GWP and the minimum given to the lowest potential feature. The GWP map was prepared by rasterizing and overlaying of themes using the spatial analysis tool in ArcGIS 10.2. The procedure can be mathematically expressed as:

$$GWPI = \frac{SL_w \Sigma SL_r + Ge_w \Sigma Ge_r + Rf_w \Sigma Rf_r + DD_w \Sigma DD_r + LU_w \Sigma LU_r + LI_w \Sigma LI_r + SO_w \Sigma SO_r + GM_w \Sigma GM_r + AL_w \Sigma AL_r}{\Sigma w + \Sigma r}$$

Where, GWPI = GWP index; SL_w , Ge_w , Rf_w , DD_w , LU_w , SO_w , GM_w , AL_w represent the normalized weight of slope, geology, rainfall, drainage density, land use land cover, soil, geomorphology and altitude respectively. SL_r , Ge_r , Rf_r , DD_r , LU_r , SO_r , GM_r , AL_r represent the normalized rank of slope, geology, rainfall, drainage density, land use land cover, soil, geomorphology and altitude respectively. The weights were normalized such that $\Sigma w = 1$ and $\Sigma r = 1$.

RESULTS AND DISCUSSION

Slope: Slope defines the variation of elevation in a particular area which influences the runoff (Naghbiet al., 2016). Slope plays a key role in the groundwater occurrence as infiltration is inversely related to slope. A break in the slope (i.e. steep slope followed by gentler slope) generally promotes an appreciable groundwater infiltration (Saraf and Choudhary, 1998). Based on slope, the study area has been divided into five slope classes, i.e. <10°, 10-20°, 20-30°, 30-40° and >40°. The slope map of the study area (fig. 2A) reveals that the major portion of the study area is dominated by a gentle slope of less than 10° covering an area of 36.06% occupying the southern part of the study area. However, the northern part is covered by steep slope of more than 40° covering an area of 31.73%.

Altitude: The altitude of an area has marked effect on the GWP of an area. Water tends to store at lower topography rather than the higher topography. Higher the elevation lesser the groundwater potential and vice versa (Gedebo et al., 2006). The study area is classified into four categories on the basis of elevation (Fig. 2B) i.e., <2000, 2000-2500, 2500-3000, >3000. Most of the area falls under lower altitude zone of <

2000 m with an area of 66.7% occupying southern part of the watershed. The northern part of the watershed has an altitude range of 2000-2500 m and 2500-3000 m covering an area of 6.04% and 27.2%, respectively.

Drainage density: Drainage density is an inverse function of permeability. Low drainage density is therefore related to higher recharge and higher GWP. Surface water bodies like river, ponds, etc., can act as recharge zones enhancing the GWP in the neighbourhood (Karanth, 1987). The resulting drainage density map of the area (Fig. 2C) was grouped into five classes such as $<1 \text{ km/km}^2$, $1-2 \text{ km/km}^2$, $2-3 \text{ km/km}^2$, $3-4 \text{ km/km}^2$ and $>4 \text{ km/km}^2$. Most of the area (49.85%) falls in low drainage density of $<1 \text{ km/km}^2$ occupying southern part of the watershed. However the northern part is covered by a drainage density range of $1-2 \text{ km/km}^2$ and $2-3 \text{ km/km}^2$ covering an area of 37.35 and 12.07% respectively.

Rainfall: Rainfall is one of the major sources for groundwater. The high rainfall amounts imply the possibility of high groundwater recharge thus high GWP zones while low rainfall indicates low groundwater recharge thus low GWP (Mwega et al., 2013). Spatial distribution map of rainfall was generated using annual rainfall data and four rainfall zones were identified (Fig. 2D). The rainfall distribution in the study area ranges from 900 to 1000 mm while most of the area falls in the rainfall distribution zone of $>1000 \text{ mm}$.

Geology: The geological setup of an area plays a vital role in the distribution and occurrence of groundwater (Krishnamurthy and Srinivas, 1995). Lithology affects the groundwater recharge by controlling the percolation of water flow and aquifer characteristics (El-Baz et al., 1995). Five geological types of alluvium, karewa formation, panjal trap, triassic limestone and zewan formation have been found. The study area is mostly dominated by karewa formations covering an area of 6150 ha (37.52%) occupying southern part of the watershed followed by zewan formation and alluvium (Fig. 2E). The northern part of the watershed is covered by zewan formation and panjal traps covering an area of 4951 and 340 ha, respectively.

Geomorphology: Geomorphology and landforms have a dominant role in the movement and storage of groundwater (Dinesh Kumar et al., 2007). Geomorphological features combined with structures and lithology controls the occurrence, movement and quality of groundwater. Evolution of landforms is useful to understand the occurrence of porous and permeable zones. Therefore, geomorphology of the study area is an essential component to be considered for groundwater recharging (Senanayake et al., 2016). The broad geomorphic features identified in the study area are alluvial plains, mountainous areas, valleys and karewa lands (Fig. 2F).

Soil: Soil is the one of the primary factor which determines the amount of groundwater. Soil characteristics have a considerable role on the infiltration of water. The rate of infiltration largely depends on the grain size of soils. Soil properties influence the relationship between runoff and infiltration rates which in turn controls the degree of permeability that determines the GWP (Tesfaye, 2010). Three major types of soil textural classes were identified in the study area i.e. sandy loam, clayey loam and silty loam (Fig. 2G).

Land Use Land Cover: LULC determines the amount of precipitation that reaches the water table to recharge groundwater. The major changes in LULC that affect hydrology are change in forest cover, intensification of agriculture, drainage of wetlands and urbanization (De Roo et al., 2001). The outcome of this alteration is typically reflected by increase in volume and rate of surface runoff and decrease in groundwater recharge and base flow (Moscrip and Montgomery, 1997). The study area was classified into 15 LULC classes (Fig. 2H) namely, agriculture field, barren land, built up, scrubland, meadows, maize fields, horticulture, saffron-horticulture (dual crop), saffron fields, vegetable fields, mixed plantation, water body, wetland and closed forests.

Lineament: Lineament density map is a measure of quantitative length of linear feature per unit area expressed in a grid which can indirectly reveal the GWPs as the presence of lineaments usually denotes a permeable zone (Sitender and Rajeshwari, 2010). The study of lineaments has proved to be very effective to locate GWP zones (Rao et al., 2004). Areas with high lineament density are good for GWP (Haridas et al., 1998). If lineament density is high, then higher will be the rate of infiltration whereas low density leads to more runoff (Kumar et al., 1999). In the study area, the lineament density was in the ranges from 1.5 km/km^2 to 3.5 km/km^2 (Fig. 2I).

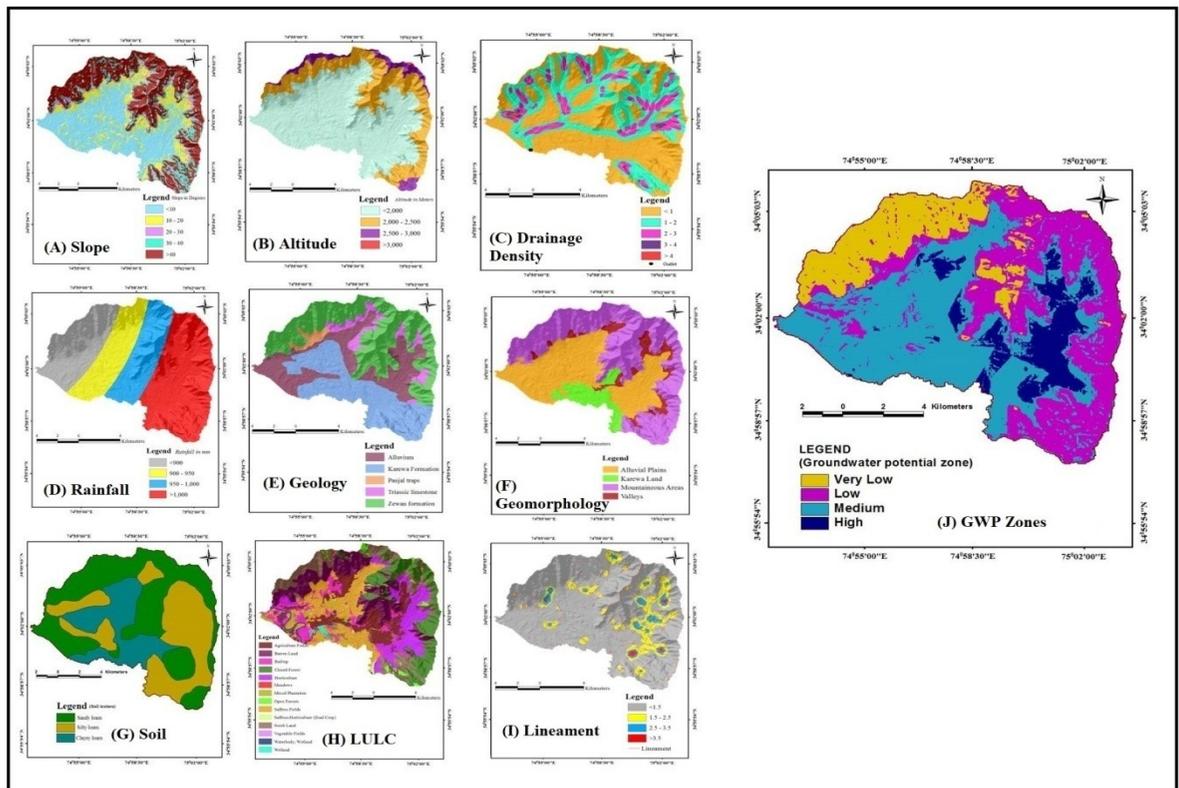


Fig. 2: Groundwater contributing factors and GWP Map of Pampore watershed

GROUNDWATER POTENTIAL ZONES

Four GWP zones namely high, medium, low and very low were identified in Pampore watershed on the basis of the MCE of different themes. These zones are discussed in the following section.

High GWP Zone: This zone covers an area of 2525 ha (15.404%). The high GWP zone constitutes gentle slope (<10°), low drainage density (<1km/km²), moderate to high lineament density (>3.5km/km²), alluvial plains and high rainfall zone (>1000mm). These factors are considered to be the key parameters for high GWP as they facilitate high infiltration and recharge.

Medium GWP Zone: This zone covers an area of 5475 ha (33.402%) of the watershed. This zone is characterized by slope classes of <10° and 10-20°, rainfall zone of 950-1000mm with the dominant altitude of more than 2000m, clayey soil, alluvium and karewa formations. The drainage density (<1km/km²), and lineament density (1.5-2.5km/km²) is moderate while land use is dominated by agriculture fields. Taking all these parameters into consideration, the GWP is found to be moderate in this zone.

Low GWP Zone: This zone covers an area of 6419ha (39.161%) of the watershed and is characterized by steep slope, high drainage density, barren land, mountainous areas, Zewan formations, Triassic limestone, fewer lineaments, barren land and an altitude range of (2000-3000 m) which results in low GWP.

Very Low GWP Zone: This zone covers an area of 1972 ha (12.030%) of the watershed and is associated with low rainfall (<900mm), steep slopes, barren land, mountainous areas, Zewan formations, very high drainage density (>4km/km²) and very few lineaments which act as run off zones with little infiltration to recharge groundwater.

CONCLUSIONS

Groundwater is a subsurface phenomenon. The exploration of groundwater using traditional methods is not only tedious but also time and labour intensive. However, there are a number of surface features which give indirect evidences of groundwater potential. These surface features can be mapped and analysed using remote sensing and GIS more conveniently and accurately. The present work accentuated the expediency of remote sensing and GIS applications in groundwater studies, especially in the identification of GWP zones in Pampore watershed. Since different surface features have varying influence on groundwater occurrence, a multi-criteria evaluation approach was adopted for the identification of GWP zones. Knowledge-based weights and ranks were normalized, and a weighted linear combination technique was adopted to determine the GWP zones. Such a zonation assumes importance in planning strategies for effective

management of the water resources. The four zones ranging from high to very low have been identified in the study area taking into consideration nine parameters with highest weight nine given to slope and lowest weight of one to altitude. From the results, it has been inferred that the study area is mostly dominated by low GWP (39.16%) followed by medium GWP (33.402%), high GWP (15.40%) and very low GWP (12.03%).

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