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RESEARCH ARTICLE

# DELINEATION OF THE GROUNDWATER POTENTIAL USING REMOTE SENSING AND GIS: A CASE STUDY OF ULHAS BASIN, MAHARASHTRA, INDIA

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KEY WORDS: Groundwater; Remote Sensing; GIS; Ulhas

ABSTRACT: Groundwater is one of the most valuable natural resources which is essential for the environmental, biological and socio-economic activities. The present paper aims to delineate groundwater potential of Ulhas basin in India through remote sensing and geographical information system. Several groundwater influencing factors such as geology, geomorphology, slope, landuse, rainfall, lineaments are mapped in GIS environment. Later, these factors were ranked on the basis of their influence on the groundwater potential of a region. After that all these factors were integrated together in GIS environment to prepare the groundwater potential map of Ulhas basin. By implementing influencing factor, it is observed that about 21%, 50% and 29% areas are falling under high, moderate, and low groundwater potential zones, correspondingly. The present study is highly valuable to the policymakers, administrative bodies, engineers for management of groundwater and preparing sustainable water resource plans in Ulhas basin. Additionally, the present paper will help to construct artificial groundwater recharge plan in the study area.

## 1. INTRODUCTION

About 71% of the Earth's surface is covered by water, within that 97% water is salt, 2% water is glaciers in the polar region and only 1% is a form of stream channels and groundwater (WWAP 2009). Surface water is highly vulnerable to various pollutants. Hence, surface water in many places is not a good option for the human consumption and economic activities (Todd and Mays 2005; Hoque *et al*. 2009; Babiker *et al*. 2007; Mogaji *et al*. 2015). Hence, management of freshwater is very significant in order to prevent severe water scarcity in arid and semi-arid regions as well as humid and sub humid region (Das and Pardeshi 2018a).

The present paper deals with groundwater potential of Ulhas river basins in India. The area considered for study that is Ulhas river basins fall in sub humid to humid climatic condition (Doke *et al*. 2018). Watershed development is a high priority in this region mainly due to the erratic rainfall pattern, occurrences of landslides and freshwater resource scarcity. To make a comprehensive plan, understanding the topography, denudation, lithology and geological structures are very important which also provide significant information about the potential of groundwater resource in an area (Sreedevi *et al*. 2009; Raj *et al*. 2017).

The geology, geomorphology, slope, soil texture, drainage density, lineament concentration, rainfall and land use of an area are influence on the availability of ground water. (Sander *et al.* 1996; Nag 2005; Sener *et al.* 2005; Solomon and Quiel 2006; Ganapuram *et al.* 2009; Singh *et al.* 2011b; Magesh *et al.* 2012; Mukherjee *et al.* 2012; Das *et al.* 2017, 2018a; Das and Pardeshi 2018b, 2018c). Groundwater occurrence, movement and storage in an area is controlled by the geological and geomorphological setup of the area. The hydrogeological setting of the area is also affected by geomorphological and geological factors directly or indirectly. Whereas, the amount of runoff, infiltration and rate of percolation are governed through the physiographic elements such as relief and slope.

Many techniques are used for assessment of ground water such as Analytic Hierarchy Process (AHP), Fuzzy logic, Weighted overlay analysis and Multi-Criteria Decision Making Technique (MFT). Recently, around the world, many scholars have used RS and GIS techniques for identification of the groundwater potential zones (Sener *et al.* 2005; Shaban *et al.* 2006; Dinesh Kumar *et al.* 2007; Yeh *et al.* 2009; Chenini *et al.* 2010; Machiwal *et al.* 2011; Magesh *et al.* 2012; Basavarajappa *et al.* 2013; Machiwal and Singh, 2015). A qualitative estimation of groundwater resources is done through the tools in Geoinformatics and Multi-Criteria Decision Making Technique (MFT) (Al-Adamat *et al.* 2003; Srivastava and Bhattacharya 2006; Madrucci *et al.* 2008; Nagarajan and Singh 2009; Avtar *et al.* 2010; Machiwal *et al.* 2010; Oh *et al.* 2011; Adiat *et al.* 2012; Magesh *et al.* 2012; Mukherjee *et al.* 2012; Nag and Ghosh 2012; Agarwal *et al.* 2013; Deepika *et al.* 2013; Gumma and Pavelic 2013; Bagyaraj *et al.* 2013; Mahmoud *et al.* 2014; Dhar *et al.* 2015; Zaidi *et al.* 2015; Agarwal and Garg 2016; Sahoo *et al.* 2016; Senanayake *et al.* 2016).

Similar approach can be used to identify artificial groundwater recharge zones (Ravi Shankar and Mohan 2005; Chowdhury *et al.* 2010). In this study, along with geoinformatic tools and influence techniques are utilized for delineation of GWPZs. Weighted overlay analysis techniques for the delineation and for identification of ground water potential zones are used by many scholars (Cheng-Haw Lee *et al.* 2008; Deepesh Machiwal *et al.* 2010; Jobin Thomas *et al.* 2011; Prabir Mukherjee *et al.* 2012; Murugesan Bagyaraj *et al.* 2012; Das *et al.* 2017).

The remote sensing and GIS techniques play a vibrant role in the assessment and the management of Earth's natural resources (Das *et al.* 2018). Currently these techniques are highly cost-effective and less time-consuming to understand the groundwater potential of a region (Murthy 2000; Leblanc *et al.* 2003; Jha and Peiffer 2006; Prasad *et al.* 2008; Pradhan 2009; Arkoprovo *et al.* 2012; Manap *et al.* 2013; Mallick *et al.* 2015; Rahmati *et al.* 2015; Das *et al.* 2017). The many previous research scholars represent the satisfactory result in the delineation of groundwater potential zones using the different geo environmental special layers. (Krishnamurthy *et al.* 1996; Rao and Jugran 2003; Lokesha *et al.* 2005; Khan *et al.* 2006; Solomon and Quiel 2006; Avtar *et al.* 2010; Dar *et al.* 2010; Jha *et al.* 2010; Elewa and Qaddah 2011; Magesh *et al.* 2012; Bagyaraj *et al.* 2013; Rahmati *et al.* 2015; Kirubakaran *et al.* 2016; Roy and Sahu 2016; Tahmassebipoor *et al.* 2016). Hence, an attempt has been made in this study to demarcate different groundwater potential areas of the Ulhas basin by using influencing techniques in GIS environment.

## 2. STUDY AREA

The Ulhas River is a west flowing river located in Western Maharashtra. It's originates in a valley north of the Rajmachi hills, its mountain streams draining the northern slope of hills and it is a part of the Western Ghats. Lactated in the Raigad district of Maharashtra, India. The Ulhas basin lies between North latitudes of 18° 44' to 19° 42' and East longitudes of 72° 45' to 73° 48' (Fig.1). The average area of Ulhas river basin is 4,637 km2, it is covers Thane, Raigad and Pune districts of Maharashtra. The mean source of water is South-West monsoon flowing in the months of June to October and the average rainfall is about 2,943 mm. The major tributaries of Ulhas basin is Kalu and Bhasta. Its covers 55.7% of the total catchment area of Ulhas basin. The total length of the river from its origin to its outfall in the Arabian Sea is 122 km.

The Ulhas River is main source of drinking water of three big Municipal Corporation such as Badlapur, Navi Mumbai and Kalyan Dombivali.

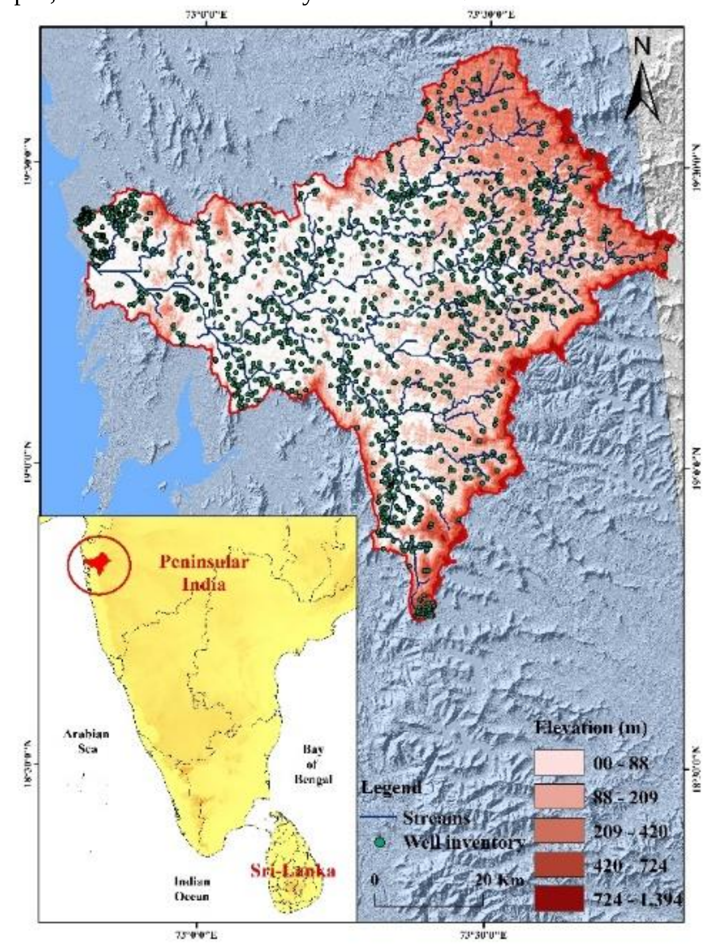


Fig. 1 Location map of the study area with reference to Maharashtra State and India.

## 3. DATA AND METHODOLOGY GEOSPATIAL DATABASE PREPARATION

Figure 2 shown the methodology which was adopt for demarcate different groundwater prospect zones in Ulhas basin. Using the geological quadrangles, Geology map of the Ulhas basin was prepared, and the geological quadrangles were acquired from the Geological Survey of India (GSI). Drainage network map of the study area was drawn by using SRTM DEM in ArcGIS 10.3 software. Hydrology tools were employed to delineate drainage network. The grid-based rainfall data (1901 to 2013, 0.25 * 0.25 degree) acquired from the Indian Metrology Department, Pune (IMD) to prepare rainfall distribution map. Soil texture data were acquired from National Bureau of Soil Survey (NBSS) to prepare the soil texture map of the Ulhas basin. SRTM DEM was processed in ArcGIS under spatial analysis tool to prepare slope map, Elevation map and Cartosat DEM use for the extraction for lineament. Lineament density map prepped with the help of rockwork software. Lineament density map prepared in ArcGis 15 software.

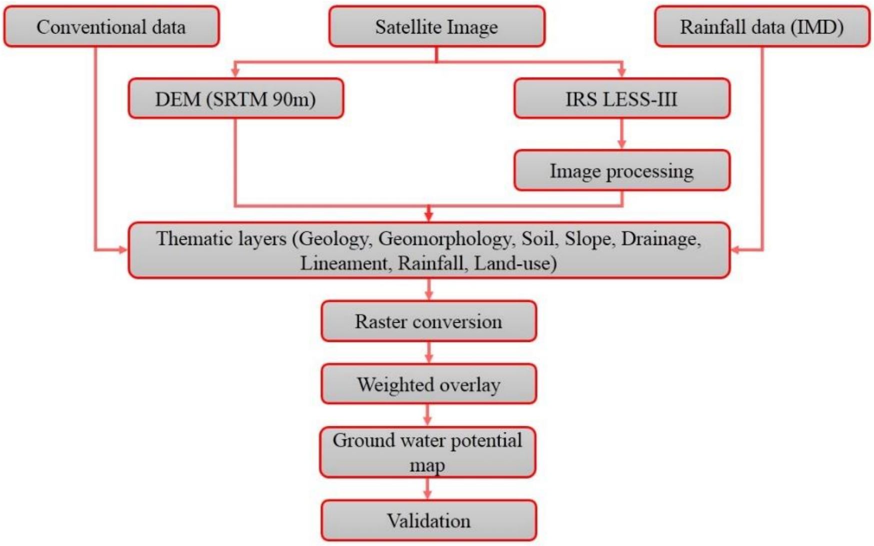


Fig. 2 Methodology considered for the present study

IRS LISS-III images of 23.5 m spatial resolution were considered in this study for the preparation of land-use map of the Ulhas basin using ERDAS Imagine 2014 software.

## 4. INFLUENCING FACTORS

All the thematic maps created previously were resampled into raster layers of 30-m spatial resolution. After that, interrelationship was made between all these factors and the weights assigned to each factor depending on their interrelationship and influence capability (Fig. 3). The interrelationship is adapted in this study based on the prior knowledge of different influencing factors for groundwater potential in different regions using the extensive literature review (Krishnamurthy *et al.* 1996; Rao and Jugran 2003; Lokesha *et al.* 2005;

Solomon and Quiel 2006; Avtar *et al.* 2010; Jha *et al.* 2010; Magesh *et al.* 2012; Bagyaraj *et al.* 2013; Rahmati *et al.* 2015; Tahmassebipoor *et al.* 2016; Das *et al.* 2017).

Based on the interrelationship among all factors, a score of 1 and a score of 0.5 were assigned to the parameters for successfully influencing other parameter(s) directly and indirectly according to its strength (Yeh *et al.* 2009) (Table 1). For instance, in our study area, lithology (mainly mafic basalt) is having a direct relationship with four factors for groundwater potential (lineament, drainage, soil, and land use). Therefore, a value of 4 was assigned for lithology. Similarly, geomorphology (Coastal Plain, Lava Plateau, Ridges/Hill, Rocky benches, Slope facets) has major influence on drainage network, soil and land use with minor impact on slope; hence, weight of 3 for major influences and 0.5 for minor influence was assigned to geomorphology.

Table 1 Influencing factors, their major-minor effects and corresponding scores (*Source:* Modified after Magesh *et al.* (2012), Das *et al.* (2017))

| Factors | Major effect ($Mj$) | Minor effect ($Mi$) | Proposed value ($Mj$+$Mi$) | Proposed score for each factor ($Pi$) |
|---|---|---|---|---|
| Geology | 1+1+1+1 | 0 | 4 | 18 |
| Geomorphology | 1+1+1 | 0.5 | 3.5 | 16 |
| Land-use pattern | 1+1 | 0.5+0.5+0.5 | 3.5 | 16 |
| Slope | 1+1 | 0.5+0.5 | 3 | 14 |
| Drainage density | 1+1 | 0.5 | 2.5 | 11 |
| Lineament density | 1+1 | 0 | 2 | 9 |
| Rainfall | 1 | 0.5+0.5 | 2 | 9 |
| Soil texture | 1 | 0.5 | 1.5 | 7 |
| | | | Σ22 | Σ100 |

However, the interrelationship among all these factors is changeable subject to the different characters of lithology, geomorphology and land use with area. The given formula was used to calculate the scores for each influencing factor (Das *et al.* 2017):

$$[(M_j+ M_i ) / (\sum (M_j+M_i )]\times 100 \tag{1}$$

Where Mj represents major interrelations among two factors and Mi represents minor interrelation among two factors. Above mentation parameters thematic were integrated into ArcGIS software; after computation of scores, rank classification was done by dividing the previous scores (Pi) by the number of classifications in each factor. The higher infusing factors gates higher score of weight (Pi) was assigned and the scores were reduced equally according to the previous calculation (Table 2). For instance, geology is having a score of 16 as weight and the study area is characterized four types of geological categories (basalt, weather basalt, marine sediment alluvium). Therefore, the first type of geology having higher influence gets a score of 18, while the second one gets 16.

Wi of first class = Pi

[e.g. Pi of lithology 18; notice Table 1 where the ranks are shown by Pi. Therefore, Wi of first class of lithology=Pi value=18]

Wi of second class = Wi of first class - (Pi⁄n)

[e.g. 16-(18/2)=9] [notice that lithology has 2 class; therefore, n=2]

Wi of first class = P Wi of second class = Wi of first class - Pi⁄n)
Wi of third class = Wi of second class - (Pi⁄n)
where Wi is the rank value of each class, Pi the weight of each factor, and n is the total number of classes in each factor.
Thereafter, weighted overlay was done to delineate groundwater potential map of the Ulhas basin by using the following equation (Das *et al.* 2017):

$$\text{Priority zone (P)} = \sum_{i=1}^{n} (\text{Pi} * \text{Wi}) \quad (2)$$

Where P represents the priority zones, Pi represents weight of each factor, and Wi represents rank of each class.

## 5. RESULT AND DISCUSSION

Eight different influencing factors such as lithology, geomorphology, drainage, soil, lineaments, slope, rainfall and land use are inspected to demarcate different groundwater prospect zones of the Ulhas basin. Below, a detailed discussion is given based on the results of this study

### 5.1. Geology

The Ulhas basin fall under four group of geological formation, which is (i) Alluvium; (ii) Basalt; (iii) Marine sediment; and (iv) Weathered basalt (Fig.3). Extensive basalt rock of the Cretaceous–Tertiary period is the primary rock type of Ulhas basin. This fine and thick alluvium is deposited small patches in eastern part of basin. West side of the basin near the seacoast marine sediment are deposited.

### 5.2. Geomorphology

The study area shows five major geomorphic divisions which are coastal plain, lava plateau, ridges/hills, rocky beaches and slope facets (Fig. 4). Western part of the basin shows coastal plain and centurial part covers the rocky benches. More than 50 percent area covers the Ridges or hills. Eastern parts of basin cover lava plateau and slope facets.

### 5.3. Land use

The major land-use patterns in the Ulhas basin are scrub land (35.43%), barren land (30.28%), built up area cove (14.95%), agricultural land (12.55%), natural vegetation (5.15%), and water bodies (1.64%) (Fig. 5). Regions with very high built-up and concrete constructions are bad for groundwater potential because of more surface run-off, while agricultural lands are good due to the availability of loose soil on the surface (Singh *et al.* 2010, 2011a; Das *et al.* 2017).

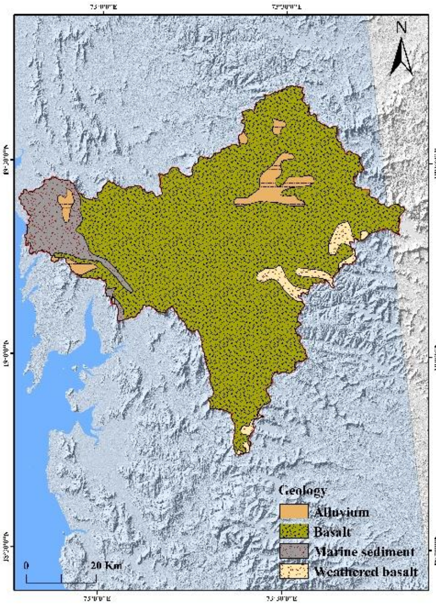


Fig. 3 Geology map of the study area

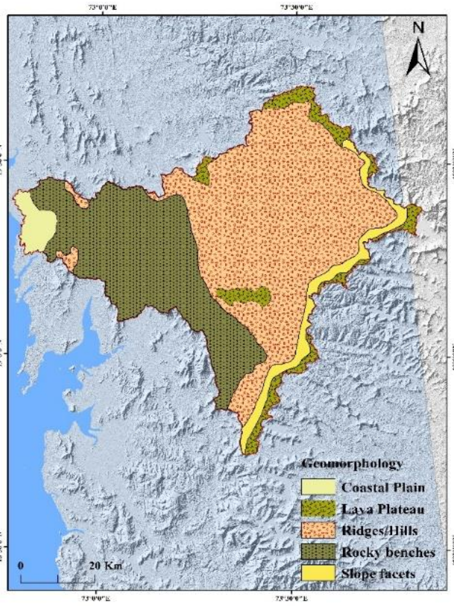


Fig. 4 Geomorphology map of the study area

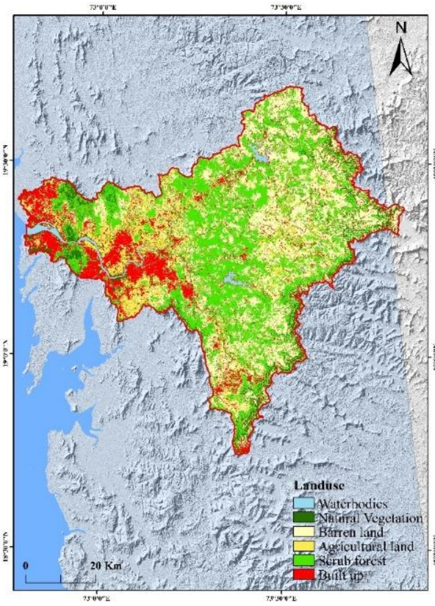


Fig.5 Land-use map of the study area

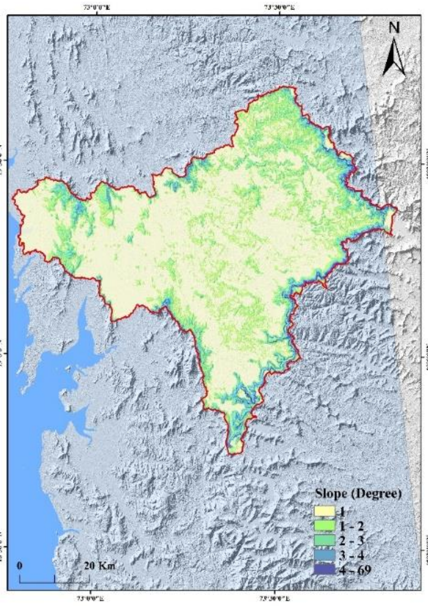


Fig.6 Slope map of study area

### 5.4. Slope

The slope plays a vital role in the delineation of ground water zonation (Fig.6). The genital slope helps increase ground water as verses steep slope. Rapid run-off occurs in the case of steep slope due to the higher velocity of the water (Das, 2018). In the gentle slope region, the water becomes stagnant in a particular place for a longer duration which influences water to penetrate into soil layers (Das, 2018).

### 5.5. Drainage density

Drainage density is the total length of streams per unit area (Avtar *et al.* 2011a). Drainage density map of Ulhas basin is intended by utilizing the line density tool in ArcGIS. Depending on the result, five classes are prepared. Figure 7 illustrates drainage density map where higher density is found in the central and the eastern section of the Ulhas river basin.

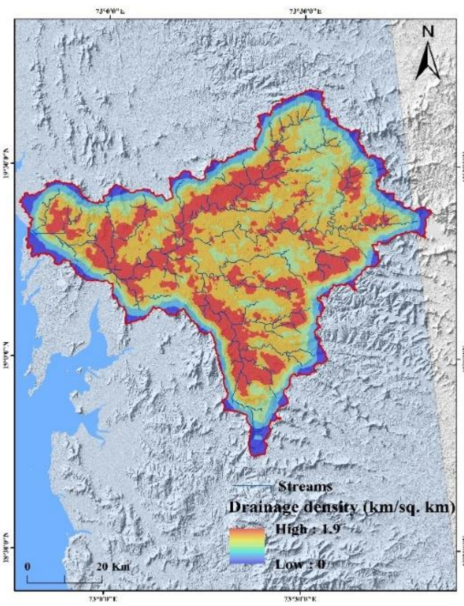


Fig. 7 Drainage density map of study area

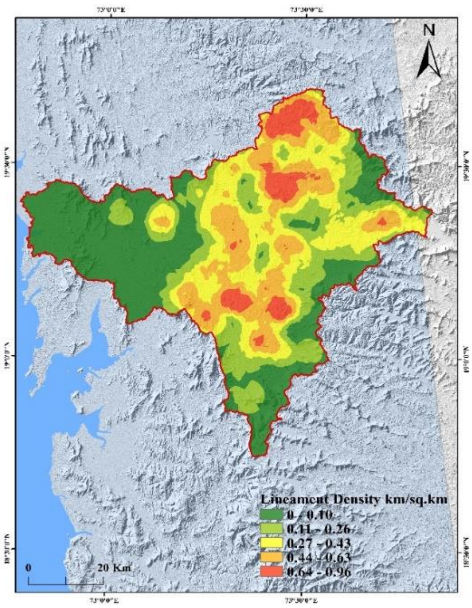


Fig.8 Lineament density map of study area

Several studies suggest that regions having lower drainage density are having more groundwater potential as run-off is higher on the impermeable rock (Bagyaraj *et al.* 2013; Jenifer and Jha 2017; Thomas and Duraisamy 2017).

### 5.6. Lineament density

Lineaments are basically the weakness of topography such as joints, cracks, faults and shears. In hard-rock lithology due to lower porosity of terrain, groundwater potentiality generally depends on other structural features (Kumanan and Ramasamy 2003; Avtar *et al.* 2011b; Singh *et al.* 2011b; Das and Pardeshi 2018b, 2018c; Das *et al.* 2018). Hence, the lineaments play a major role in groundwater potential as the structural weakness increases the infiltration rate. The higher density area represents the good groundwater potential. Figure 8 illustrates the lineament density map of the study area where it can be observed that the center part of study area is characterized by very dense lineaments density.

### 5.7. Rainfall

Ulhas basin is a part of sub humid to humid climatic morphogenetic region. Average annual rainfall of the study area is about 2943 mm. Figure 9 represent rainfall distribution map, average annual rainfall distribution of 63 years. Mainly the rainfall occurs in June to September, it's a monsoon season. The average rainfall is high, but the geological formation creates a water scarcity. Almost no rainfall occurs for the period of January-May, and during this time severe water resource scarcity occurs in the study area due to lack of water availability. South section of the Ulhas basin shows higher annual rainfall due to the south-west monsoon which brings high amount of water vapors in this area. The eastern part of the Ulhas basin experiences low amount of rainfall.

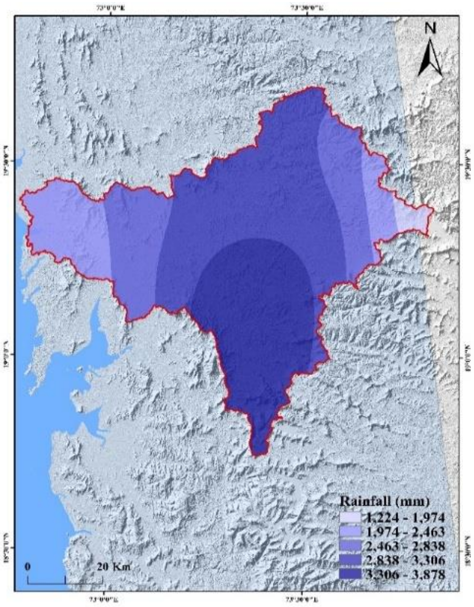


Fig. 9 Rainfall distribution map of study area

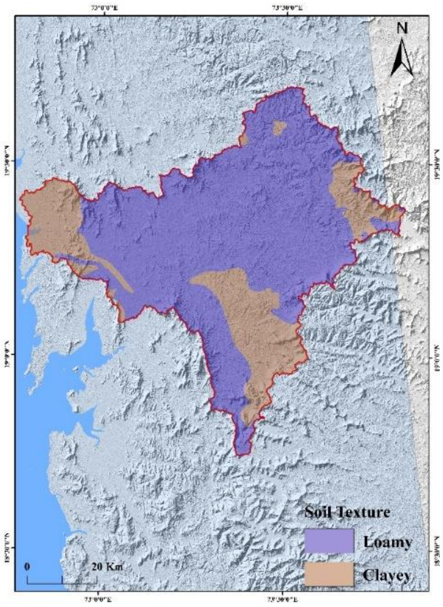


Fig.10 Soil texture map of study area

### 5.8. Soil

Soil texture and depth are having a major impact on the groundwater potentiality of an area (Mehra *et al.* 2016; Mehra and Singh 2018). Soil distribution map of the Ulhas basin was prepared from the soil map of Maharashtra (Fig. 10). The major soil texture found in the study area is clay and loam. The thickness of soil varies place to place. Loamy soil texture coves highest area of study region.

### 5.9. Delineation of different groundwater potential areas

By using remote sensing and GIS, several influencing factors such as lithology, geomorphology, slope and rainfall were integrated to demarcate groundwater potential zones in Ulhas basin, Maharashtra. All these factors were grouped, and the weighted overlay was performed using influencing factors techniques. Depending on the results that came out in ArcGIS, the entire study area was divided into three categories of different groundwater potentials: high, moderate, low.

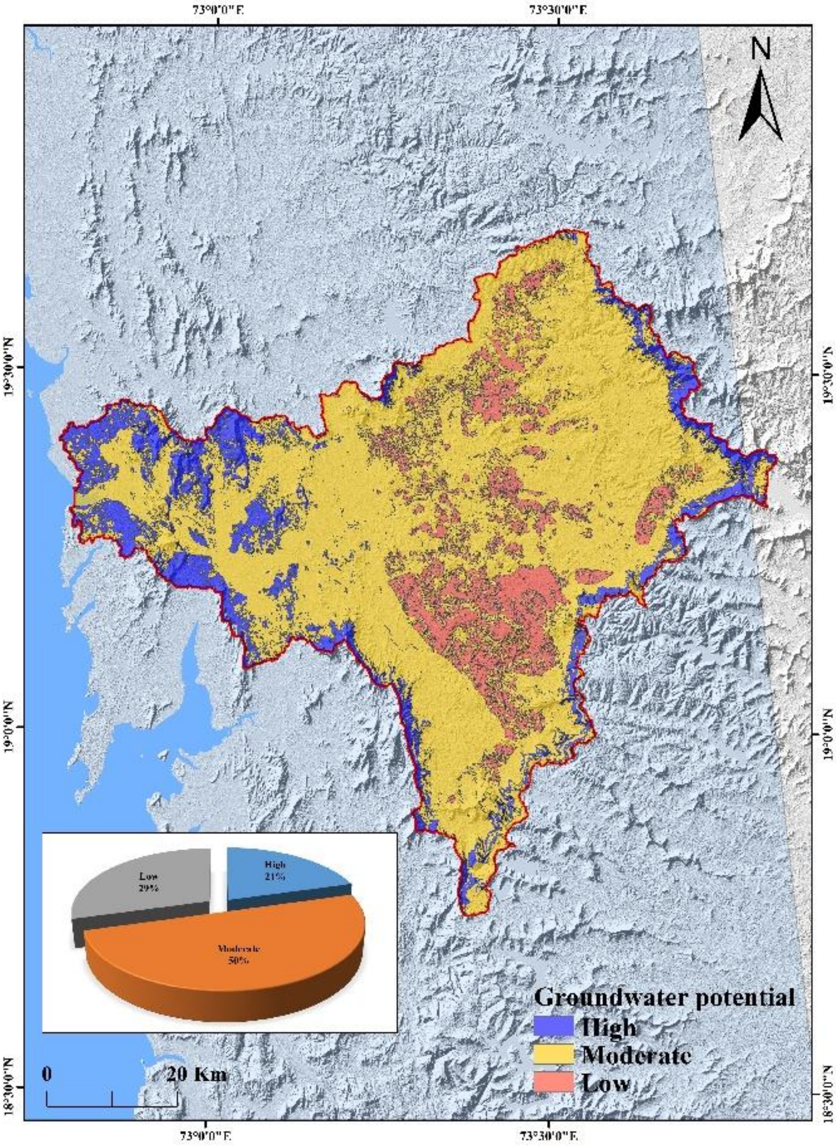


Fig.11 Groundwater potential map of the study area using influencing factors method.

Figure 11 illustrates the groundwater recharge potential map of the Ulhas basin through influencing factor technique. By implementing influencing factor, it is observed that about 21%, 50% and 29% areas are falling under high, moderate, and low groundwater potential zones, correspondingly.

## 6. VALIDATION OF THE RESULTS

Validation of the data is one of the most essential works after designing any model in order to check proficiency of the predicted results. To validate the groundwater recharge zones of Ulhas basin, at first all the major locations are plotted in the groundwater potential maps. Plotting the major villages and town made it easier to compare the map with existing groundwater reports of CGWB (2014) for Thane district. It is observed that groundwater potential is higher in the central coastal part of Ulha basin.

## 7. CONCLUSION

Remote sensing and GIS techniques are found to be proficient tools to demarcate groundwater potential zones of Ulhas basin, which save money, time and provide quite an accurate result. The present study represents that satellite images and different data sets, different thematic layers are crate and its useful for delineation of ground potential zone identification. The different factors such as lithology, geomorphology, soil, drainage density, lineament concentration, slope, rainfall and land-use pattern used for identification of potential ground water zones. GIS software play a vital role in the present study. The present result shows that entire Ulhas basin area is categorized into three different zones. Witch was high, moderate, low potential for ground water. The regions having good groundwater potential in the resulting maps may be selected for artificial recharge projects by government or other non-government authorities. The study useful for the watershed management. Study area represent dense population density. The three big Municipal Corporation such as Badlapur, Navi Mumbai and Kalyan Dombivali located in Ulhas river basin. So in future requirement of drinking water increased day by day. It is also useful for the feature planning for ground water recharge activity.

## LITERATURE

Adiat, K.A.N., Nawawi, M.N.M., Abdullah, K. (2012). Assessing the accuracy of GIS-based elementary multi criteria decision analysis as a spatial prediction tool - a case of predicting potential zones of sustainable groundwater resources. J Hydrol 440-441, 75-89.

Agarwal, E., Agarwal, R., Garg, R.D., Garg, P.K. (2013a). Delineation of groundwater potential zone: an AHP/ANP approach. J Earth Syst Sci 122(3), 887-898.

Agarwal, R., Garg, P.K. (2016) Remote sensing and GIS based groundwater potential & recharge zones mapping using multi - criteria decision making technique. Water Resour Manag 30, 243-260.

Al-Adamat, R.A.N., Foster, I.D.L., Baban, S.M.J. (2003). Groundwater vulnerability and risk mapping for the basaltic aquifer of the Azraq basin of Jordan using GIS, remote sensing and DRASTIC. Appl Geogr 23(4), 303-324

Altin, T.B., Altin, B.N. (2011). Development and morphometry of drainage network in volcanic terrain, Central Anatolia, Turkey. Geomorphology 125, 485-503.

Arkoprovo, B., Adarsa, J., Shashi Prakash S. (2012). Delineation of groundwater potential zones using satellite remote sensing and geographic information techniques: a case study from Ganjam district, Orissa, India. Res J Recent Sci 9, 59-66.

Avtar, R., Singh, C.K., Shashtri, S., Singh, A., Mukherjee, S. (2010). Identification and analysis of groundwater potential zones in Ken–Betwa river linking area using remote sensing and geographic information system. Geocarto Int 25(5), 379-396.

Bagyaraj, M., Gurugnanam, B. (2011). Significance of morphometric studies, soil characteristics, erosion phenomena and landform processes using remote sensing and GIS for Kodaikanal Hills. Res J Environ Earth Sci 3(2011), 221-233.

Bagyaraj, M., Ramkumar, T., Benkatramanan, S., Gurugannam, B. (2013). Application of remote sensing and GIS analysis for identifying groundwater potential zones in parts of Kodaikanal Taluk, South India. Front Earth Sci 7(1), 65-75.

Basavarajappa, H.T., Dinakar, S., Satish, M.V., Nagesh, D., Balasubramanian, A., Manjunatha, M.C. (2013). Delineation of groundwater potential zones in Hard rock Terrain of Kollegal Shear Zone. (KSZ). South India using Remote Sensing and GIS. International Journal of Civil Engineering and Technology 5(12), 305-315.

Chen, C.Y., Yu, F.C. (2011). Morphometric analysis of debris flows and their source areas using GIS. Geomorphology 129:387-397

Chowdhury, A., Jha, M.K., Chowdary, V.M. (2010). Delineation of groundwater recharge zones and identification of artificial recharge sites in West Medinipur district, West Bengal, using RS, GIS and MCDM techniques. Environ Earth Sci 59, 1209-1222.

Dar, I.A., Sankar, K., Dar, M.A. (2010). Remote sensing technology and geographic information system modeling: an integrated approach towards the mapping of groundwater potential zones in Hardrock terrain, Mamundiyar basin. J Hydrol 394(3), 285-295.

Das, S., Gupta, A., Ghosh, S. (2017). Exploring groundwater potential zones using MIF technique in semi-arid region: a case study of Hingoli district, Maharashtra. Spat Inf Res 25(6), 749-756.

Das, S., Pardeshi, S.D. (2018a). Morphometric analysis of Vaitarna and Ulhas river basins, Maharashtra, India: using geospatial techniques. Appl Water Sci 8(6), 158.

Das, S., Pardeshi, S.D. (2018b). Comparative analysis of lineaments extracted from Cartosat, SRTM and Aster DEM: a study based on four watersheds in Konkan region, India. Spat Inf Res 26(1), 47-57.

Das, S., Pardeshi, S.D. (2018c). Integration of different influencing factors in GIS to delineate groundwater potential areas using IF and FR techniques: a study of Pravara basin, Maharashtra, India. Appl Water Sci 8(7), 1-16.

Deepesh, M., Madan, K., Jha, Bimal C (2011). Assessment of groundwater potential in a semi-arid region of india using remote sensing,GIS and MCDM techniques. Water Resource Manage 25:1359-1386.

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.

Dhar, A., Sahoo, S., Mandal, U., Dey, S., Bishi, N., Kar, A. (2015). Hydro-environmental assessment of a regional groundwater aquifer: Hirakud command area (India). Environ Earth Sci 73(8), 4165-4178.

Dinesh Kumar, P.K., Gopinath, G., Seralathan, P. (2007). Application of remote sensing and GIS for the demarcation of groundwater potential zones of a river basin in Kerala, southwest coast of India. Int J Remote Sens 28(24), 5583-5601.

Doke, A., Pardeshi, S.D., Pardeshi, S.S., Das, S. (2018). Identification of morphogenetic regions and respective geomorphic processes: a GIS approach. Arab J Geosci 11, 1-13.

Elewa, H.H., Qaddah, A.A. (2011). Groundwater potentiality mapping in the Sinai Peninsula, Egypt, using remote sensing and GIS-watershed-based modeling. Hydrogeol J 19(3).

Ganapuram, S., Kumar, G., Krishna, I., Kahya, E., Demirel, M. (2009). Mapping of groundwater potential zones in the Musi basin using remote sensing and GIS. Adv Eng Softw 40, 506-518

Gumma, M.K., Pavelic, P. (2013). Mapping of groundwater potential zones across Ghana using remote sensing, geographic information systems, and spatial modeling. Environ Monit Assess 185(4), 3561-3579.

Hsin-Fu Yeh, Cheng-Haw Lee, Kuo-Chin Hsu,Po-Hsun Chang (2008). “GIS for assessment of the groundwater recharge potential zone”. Environ Geol 58, 185-195.

Jha, M.K., Chowdary, V.M., Chowdhury, A. (2010). Groundwater assessment in Salboni Block, West Bengal (India) using remote sensing, geographical information system and multi-criteria decision analysis techniques. Hydrogeol J 18(7), 1713-1728.

Jha, M.K., Peiffer, S. (2006). Applications of remote sensing and GIS technologies in groundwater hydrology: past, present and future. Bayreuth University Press, Bayreuth.

Khan MA, Narain P, Moharana PC (2006). Prospecting ground water resources using RS-GIS-a case study from arid western Rajasthan of India. J Indian Soc Remote Sens 34(2).

Kirubakaran, M., Johnny, J.C., Ashokraj, C., Arivazagan, S. (2016). A geostatistical approach for delineating the potential groundwater recharge zones in the hard rock terrain of Tirunelveli taluk, Tamil Nadu, India. Arab J Geosci 9, 382.

Krishnamurthy J, Kumar NV, Jayraman V, Manivel M (1996). An approach to demarcate groundwater potential zones through remote sensing and GIS. Int J Remote Sens 17(10):1867-1884

Leblanc M, Leduc C, Razack M, Lemoalle J, Dagorne D, Mofor L (2003). Application of remote sensing and GIS for groundwater modeling of large semiarid areas: example of the Lake Chad Basin, Africa. In: Hydrology of mediterranean and semiarid regions conference, Montpellier, France. Red Books Series, 278. IAHS, Wallingford, 186-192.

Lokesha N, Gopalakrishna GS, Gowdaand H, Gupta AK (2005). Delineation of groundwater potential zones in a hard rock terrain of Mysore district, Karnataka using IRS data and GIS techniques. J Indian Soc Remote Sens 33(3), 405-412.

Machiwal D, Jha MK, Mal BC (2010). Assessment of groundwater potential in a semi-arid region of India using remote sensing, GIS and MCDM techniques. Water Resour Manag 25(5), 1359-1386.

Machiwal D, Singh PK (2015). Comparing GIS-based multi-criteria decision making and Boolean logic modeling approaches for delineating groundwater recharge zones. Arab J Geosci 8(12), 10675-10691.

Madrucci V, Taioli F, de Araújo CC (2008). Groundwater favorability map using GIS multicriteria data analysis on crystalline terrain, São Paulo State, Brazil. J Hydrol 357(3-4), 153-173.

Magesh NS, Chandrasekar N, Soundranayagam JP (2012). Delineation of groundwater potential zones in Theni district, Tamil Nadu, using remote sensing, GIS and MIF techniques. Geosci Front 3(2), 189-196.

Mahmoud SH, Alazba AA, Amin MT (2014). Identification of potential sites for groundwater recharge using a GIS-based decision support system in Jazan region-Saudi Arabia. Water Resour Manag 28(10), 3319-3340.

Mallick J, Singh CK, Al-Wadi H, Ahmed M, Rahman A, Shashtri S, Mukherjee S (2015). Geospatial and geostatistical approach for groundwater potential zone delineation. Hydrol Process 29(3), 395-418.

Manap MA, Sulaiman WNA, Ramli MF, Pradhan B, Surip N (2013). A knowledge-driven GIS modeling technique for groundwater potential mapping at the Upper Langat Basin, Malaysia. Arab J Geosci 6, 1621-1637.

Mishra A, Dubey DP, Tiwari RN (2011). Morphometric analysis of Tons basin, Rewa District, Madhya Pradesh, based on watershed approach. Earth Sci India 4, 171-180.

Mukherjee P, Singh CK, Mukherjee S (2012). Delineation of groundwater potential zones in arid region of India-a remote sensing and GIS approach. Water Resour Manag 26(9).

Murthy KSR (2000). Ground water potential in a semi-arid region of Andhra Pradesh-a geographical information system approach. Int J Remote Sens 21, 1867-1884.

Murugesan B, Thirunavukkarasu R, Senapathi V, Balasubramanian G (2012). Application of remote sensing and GIS analysis for groundwater potential zone in kodaikanal Taluka, South India”. Earth Sci. 7(1), 65-75.

Nag SK (2005). Application of lineament density and hydrogeomorphology to delineate groundwater potential zones of Baghmundi block in Purulia district, West Bengal. J Indian Soc Remote Sens 33, 521-529.

Nag SK, Ghosh P (2012). Delineation of groundwater potential zone in Chhatna block, Bankura District, West Bengal, India using remote sensing and GIS techniques. Environ Earth Sci 70(5):2115-2127

Nagarajan M, Singh S (2009). Assessment of groundwater potential zones using GIS technique. J Indian Soc Remote Sens 37, 69-77.

Oh H-J, Kim Y-S, Choi J-K, Park E,Lee S (2011). GIS mapping of regional probabilistic groundwater potential in the area of Pohang City, Korea. J Hydrol 399(3-4), 158-172.

Prabir Mukherjee, Chander Kumar Singh and Saumitra Mukherjee (2011). Delineation of Groundwater Potential Zones in Arid Region of India, A Remote Sensing and GIS Approach. Water Resource Manage 26, 2643-2672.

Pradhan B (2009) Groundwater potential zonation for basaltic watersheds using satellite remote sensing data and GIS techniques. Cent Eur J Geosci 1(1), 120-129.

Prasad RK, Mondal NC, Banerjee P, Nandakumar MV, Singh VS (2008). Deciphering potential groundwater zone in hard rock through the application of GIS. Environ Geol 55(3), 467-75.

Preeja K. R., Sabu Joseph, Jobin Thomas and Vijith H (2011). Identification of Groundwater Potential Zones of a Tropical River Basin (Kerala, India) Using Remote Sensing and GIS Techniques. J Indian Soc Remote Sens. 39(1), 83-94.

Rahmati O, Samani AN, Mahdavi M, Pourghasemi HR, Zeinivand H (2015). Groundwater potential mapping at Kurdistan region of Iran using analytic hierarchy process and GIS. Arab J Geosci 8(9), 7059-7071.

Rao YS, Jugran DK (2003). Delineation of groundwater potential zones and zones of groundwater quality suitable for domestic purposes using remote sensing and GIS. Hydrol Sci J 48(5), 821-833.

Ravi Shankar MN, Mohan G (2005). A GIS based hydrogeomorphic approach for identification of site-specific artificial-recharge techniques in the Deccan Volcanic Province. J Earth Syst Sci 114(5), 505-514.

Rawat PK, Tiwari PC, Pant CC (2011). Morphometric analysis of third order river basin using high resolution satellite imagery and GIS technology: special reference to natural hazard vulnerability assessment. E-Int Sci Res J 3, 70-87.

Roy S, Sahu AS (2016). Effectiveness of basin morphometry, remote sensing, and applied geosciences on groundwater recharge potential mapping: a comparative study within a small watershed. Front Earth Sci 10(2), 274-291.

Sahoo, S., Dhar, A., Kar, A., & Ram, P. (2016). Grey analytic hierarchy process applied to effectiveness evaluation for groundwater potential zone delineation. Geocarto Int:1-18.

Sander P, Chesley M, Minor T (1996). Groundwater assessment using remote sensing and GIS in a rural groundwater project in Ghana: lessons learned. Hydrogeol J 4, 78-93.

Saxena PR, Prasad NSR (2008). Integrated land and water resources conservation and management –development plan using remote sensing and GIS of Chenvella sub-watershed, R.R. District, Andhra Pradesh, India. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. XXXVII, Part B8, Beijing, 729-732

Senanayake IP, Dissanayake DMDOK, Mayadunna BB, Weerasekera WL (2016). An approach to delineate groundwater recharge potential sites in Ambalantota, Sri Lanka using GIS techniques. Geosci Front 7(1), 115-124.

Sener E, Davraz A, Ozcelik M (2005). An integration of GIS and remote sensing in groundwater investigations: a case study in Burdur, Turkey. Hydrogeol J 13(5-6), 826-834.

Shaban A, Khawlie M, Abdallah C (2006). Use of remote sensing and GIS to determine recharge potential zones: the case of Occidental Lebanon. Hydrogeol J 14(4), 433-443.

Singh CK, Shashtri S, Singh A, Mukherjee S (2011b). Quantitative modelling of groundwater in Satluj river basin of Rupnagar district of Punjab using remote sensing and geographic information system. Environ Earth Sci 62(4), 871-881.

Solomon S, Quiel F (2006). Groundwater study using remote sensing and geographic information system (GIS) in the central highlands of Eritrea. Hydrogeol J 14(5), 729-741.

Srivastava PK, Bhattacharya AK (2006). Groundwater assessment through an integrated approach using remote sensing, GIS and resistivity techniques: a case study from a hard rock terrain. Int J Remote Sens 27(20), 4599-4620.

Tahmassebipoor N, Rahmati O, Noormohamadi F, Lee S (2016). Spatial analysis of groundwater potential using weights-of-evidence and evidential belief function models and remote sensing. Arab J Geosci 9, 79.

Yeh HF, Lee CH, Hsu KC, Chang PH (2009). GIS for the assessment of the groundwater recharge potential zone. Environ Geol 58(1), 185-195.

Zaidi FK (2011). Drainage basin morphometry for identifying zones for artificial recharge: a case study from Gagas river basin, India. J Geol Soc India 77, 160-166.

Zaidi FK, Nazzal Y, Ahmed I, Naeem M, Jafri MK (2015). Identification of potential artificial groundwater recharge zones in Northwestern Saudi Arabia using GIS and Boolean logic. J Afr Earth Sci 111, 156-169.

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