Ground water, which is the hidden water source, also plays a major role amongst fresh water resources worldwide. The scarce and precious nature of resources like ground water is not understood by sections of society resulting in costly resources spent on meeting demands. Ground water is an important source of portable water available for human consumption in the world. It is a renewable resource that can sustain various anthropogenic activities of a population, if judiciously used.

Bengaluru, considered as the green city of India is the only metropolitan city in the nation, having no perennial water source in the neighbourhood. City depends mainly on municipal water and ground water for its water requirements. Nearly half of the population depends on ground water for their daily needs. Development of a sustainable water demand plan for the city is inexpedient due to non-adherence of a master plan for the city, large amount of floating population, unsustainable usage of water resources due to lack of awareness of preservation and recycling of waste. The data and information regarding ground water for the city are collected from government agencies like BWSSB, CGWB, DMG, BBMP and Census and Statistics Department for the period 2010 to 2015. The invisible water source, ground water, its condition and availability are analysed using water table movement analysis where ground water levels and water table movements are studied for detecting the ground water conditions in the city. Various factors affecting the ground water availability viz, population density, well density and absolute population are identified to understand the influence of these components on ground water scenario of the city using multivariate analysis. The resultant depth to water level at different well locations in a region are mapped using geographic information system, GIS (Arc GIS), based on the lat long position of the well locations. Grouping of the resultant water level in appropriate ranges are done to contour the water level of ground water for a region. Based on the water level contours seasonal variation of ground water levels (pre-monsoon, monsoon and post monsoon) and ground water level fluctuation between the years 2010 and 2015 are done. Further the progression of critical areas in terms of ground water availability is assessed for a period of five years using GIS for Bengaluru.

Key words: GIS, CGWB, Bengaluru, DMG, Contour, BWSSB, BBMP.

Ground water, which is the hidden water source, also plays major role amongst fresh water resources worldwide. The scarce and precious nature of resource like ground water is not understood by sections of society resulting in costly resources spent on meeting demands. Ground water is an important source of portable water available for human consumption in the world. It is a renewable resource that can sustain various anthropogenic activities of a population, if judiciously used.

Bengaluru, considered as the green city of India is the only metropolitan city in the country where there is no perennial river water source system. The water utility, BWSSB (Bengaluru Water Supply and Sewerage Board), is bringing water from Cauvery river which is located 100 kms away from the city. Ground water, is an important variable of water supply system for Bengaluru. People are depending on ground water for their daily needs, which affects the availability of invisible, endless natural resource -ground water. Forty percent of population of Bengaluru depends on ground water as an alternate source, to meet their daily water needs (IIHS, 2014). Ground water is depleting in an alarming rate in Bengaluru urban area due to over draft (Raju et al., 2008). Unabated groundwater consumption has created critical areas, where ground water exploitation is greater than recharge (Suresh, 2001). Extensive ground water supply through private self-supply, water utility and informal water tanker business causes drastic ground water depletion in the city [IIHS, 2014].

The availability of the ground water is limited in Bengaluru, since the underlain rock formations are massive in nature. The rock formations in Bengaluru predominantly is gneiss, granite with intrusion of pegmatite, dykes etc. In their original form, these rocks do not have any primary porosity in them to hold water. Water is stored only in the top weathered zone and fractured zone. The maximum depth of water level is about...
150 to 200m. According to the Department of Mines and Geology (DMG), during the 80s, ground water was utilised to its maximum extent in Karnataka. In parts of South Karnataka, ground water has depleted below 600 feet. (Reddy, 2003).

The secondary source of water, ground water, is constrained due to lack of an integrated management approach with the multiplicity of private water suppliers doing unscientific withdrawal and supply of ground water. Lack of ground water conservation techniques due to rapid urbanization and pollution of water bodies and lakes also add stress on ground water. Central Ground Water Board (CGWB) categorises Bengaluru under super critical zone of ground water utilization resulting in low aqonic ground water potential. In a city like Bengaluru, some sparse studies are available on the current situation of ground water from Central Ground Water Board (CGWB). Also, Department of Mines and Geology holds data on the location of aquifers and ground water zone (saturated and unsaturated). Central Ground Water Board assess the ground water potential by a network of observatory wells in and around Bengaluru (CGWB, 2013). To manage the ground water resources scientifically, there is need for good database on aquifer system, aquifer geometry, aquifer parameters, ground water chemistry, etc. However, ample data on the aquifer system of the country have been generated by various agencies including CGWB. But still there are data gaps which need to be addressed to understand the microlevel ground water scenario (Vittala & Reddy, 2013).

However, development of a sustainable water demand plan for the city is difficult due to non-adherence of the master plan, large amount of floating population, unsustainable usage of water resources, and lack of awareness of preservation and recycling of water. The above said conditions have created great difficulty for master planners and the water supply board in assessing future water demand and implementing the supply plan to the areas in a meticulous manner. Also, the over exploitation of ground water in an unsustainable manner & lack of awareness among citizens towards recycling and conservation have resulted in high criticality in water resource availability and its management.

According to the study conducted by Central Groundwater Board in 2013, total groundwater draft in the district is much above the total available ground water resources leaving a gap with respect to ground water resources for future use. This overexploitation of ground water sources in Bengaluru Urban District area should need immediate attention and action plans to prevent water scarcity in future years in the district. Also, CGWB reports that ground water is over exploited in Bengaluru. Taluk wise exploitation percentage is given below (Table 1).

<table>
<thead>
<tr>
<th>Taluk</th>
<th>Stage of Development %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anekal</td>
<td>128%</td>
</tr>
<tr>
<td>Bangalore North</td>
<td>135%</td>
</tr>
<tr>
<td>Bangalore South</td>
<td>176%</td>
</tr>
<tr>
<td>Bangalore East</td>
<td>130%</td>
</tr>
</tbody>
</table>

Source: (Hegde, 2015)

STUDY AREA: The study area includes Bengaluru Urban District which is located in the South-Eastern part of Karnataka. It is the principal administrative, industrial, commercial, educational and cultural capital of the state of Karnataka. Bengaluru city is located at more than 950 m amsl (above mean sea level) (RMP, 2031). The study area includes 711 sq.km of BBMP area with 198 wards providing municipal water distribution by BWSSB (Bengaluru Water Supply and Sewerage Board) boundary of 623 sq.km (Fig.2). BBMP area lies between 12°49’34”N and 13°18’9”N lat., and 77°27’41”E and 77°47’5”E long.

OBJECTIVE: As ground water is over exploited in Bengaluru, there is significance on study of ground water levels, factors affecting ground water levels and water table movements for the city of Bengaluru. Rather than doing a complete hydro geomorphology study into the problem, attempts are done to find a cost effective and alternate way to identify the critical areas of ground water in Bengaluru by taking available water level (depth to water level) variations of wells across the city and analysing associated contours using GIS techniques. The objectives of the study include:
DELINEATING CRITICAL AREAS FOR GROUND WATER USING GIS

The major objective of the present study is to identify the ground water potential in Bengaluru urban geological area to delineate the critical zones in the city where there is a high scarcity of the alternate water source.

METHODOLOGY: Ground water is an invisible commodity and its supply is done in the city by various agencies. So, a water table movement analysis is included in the study to assess the ground water scenario in Bengaluru. The study includes the following steps,

- Calculating the resultant depth of ground water at a location with a particular latitude and longitude value

The resultant water level at the well location is calculated as follows

\[ \text{RDA} = \text{AA} - \text{DA} \]

Where Resultant Water Level (depth) at a well location A is RDA and altitude of well location is AA and DA are the depth to water level at well location A. Altitude of the well location above mean sea level (amsl) is determined from the GIS mapping methods.

- Contouring the resultant water level in a region: The RDA at different locations in a region are mapped in GIS applications based on the lat long position of the well locations. Grouping of the RDA in appropriate ranges are done to contour the water level of ground water for a region.

- Identifying the critical areas: To arrive at the composite view of ground water critical areas, geographical information systems (GIS) using ArcGIS application is used. This was necessitated due to varying jurisdictions and controls by different agencies like BBMP, BDA, BWSSB and CGWB. GIS is a set of tools for collecting, storing, retrieving, transforming and displaying spatial data from the real world for a particular set of purposes (Burrough,1986). Geographical Information System can be used for various purposes like resource management, environmental impact assessment, urban planning, scientific investigations etc. GIS technology involves essential tools to combine various maps and remote sensing information to generate various models, which are used in real time environment.

Resultant depth to water level is marked in the base map of Bengaluru and contouring has done and water table movement is analysed using GIS. The water table movement is mapped for the duration 2010 to 2015 using contouring of ground water levels with the help of GIS (Arc GIS) using the data supplied by CGWB and DMG. The resulting contours are then overlaid on BWSSB (Bengaluru Supply and Sewerage Board) divisional map of the same period to find out the real critical areas. ArcGIS application was used to map the geographic co-ordinates and its attributes using GIS techniques. The maps with all attributes were overlaid with other information/maps from other agencies in the field of water management. Also, the factors related to ground water are statistically modelled to find out a correlation of the ground water level of the wells in Bengaluru.

A schematic diagram of process step is given in Fig-1.

RESULTS AND DISCUSSION

Assessment of factors affecting ground water potential in Bengaluru: Continuous development of ground water is feasible when wells have been pumping for an appreciable time. In that case, a steady state condition will occur which facilitates continuous abstraction of ground water. In the absence of pumping, groundwater levels will continue to decline, which finally will result in the well falling dry or in a complete exhaustion of the groundwater reservoir (De Smedt,2009)
Fig. 1: Schematic diagram of methodology

### Table 2: Factors affecting ground water (GW) potential

<table>
<thead>
<tr>
<th>Contributing head</th>
<th>Contributing factors</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recharge Potential</td>
<td>Rain fall</td>
<td>Annual and seasonal rainfall (absolute and as % of normal) Actual no of rainy days as % of normal</td>
</tr>
<tr>
<td></td>
<td>Natural Water Seepage</td>
<td>Depends mainly on the type of soil and soil characteristics for seepage and retention Losses due to Evapotranspiration Land use characteristics including availability of water bodies</td>
</tr>
<tr>
<td></td>
<td>Artificial Water Seepage</td>
<td>Depends mainly on the Water harvesting methods including rainwater harvesting Seepage from Surface water distribution network</td>
</tr>
<tr>
<td>Degree of extraction</td>
<td>Anthropogenic activities</td>
<td>Major anthropogenic activities affect the usage / extraction of ground water. The following factors are contributors of the anthropogenic activities Demand or changes in demand due to population changes Alternate use of ground water including irrigation Availability of alternate water supply systems including Surface water distribution</td>
</tr>
<tr>
<td></td>
<td>Aquifers</td>
<td>Aquifers are sources of ground water extraction which needs to be carefully mapped and managed. Extraction of ground water from confined aquifers is not a sustainable practice for recharge and conservation of ground water</td>
</tr>
<tr>
<td></td>
<td>Water Table Movements</td>
<td>Ground water is not static and moves as per many factors. A careful study of water table movements denoted by the resultant Depth to Water Level in the wells give indications on areas of criticality, town planning including deciding of Surface water coverage needed for an area</td>
</tr>
</tbody>
</table>
Ground water exploration was undertaken in the district between the period from 1990 to 1996 to ascertain the presence of productive aquifer zones, quality of ground water, yield of aquifer zones and determine aquifer parameter which reveals the draft exceeding the total available groundwater resources leaving almost nil ground water resources for future use. The stage of ground water development in all the four taluks of the district is above 100 percent and are in the over exploited category (Ground water information booklet, 2013).

Ground water variation can be broadly classified into two categories:

- **Factors affecting the recharge potential**: These are the factors affecting the infiltration of water from precipitation and surface water flow.

- **Factor affecting discharge potential**: They are the factors determining the amount of water drawn from the wells in the region. (Table 2)

**Recharge Potential**: Recharge potential is the degree of addition of ground water levels for any given region. The following table (Table 3) gives the list of factors affecting the recharge potential and its degree of importance. For each of this factor, the paper gives a degree of importance, availability of data and applicability in Bengaluru.

Since most of the city area is covered by buildings, roads and pavements not much scope is there for the rainwater to recharge the ground water aquifer. Most of the rainwater which falls in the city goes as run off and very little percolates into the ground. Due to bad sewage system or no underground drainage in certain parts of the city and its environments, sewage water and industrial waste water percolates into ground contaminating the ground water resources.

**Degree of Extraction of Ground Water (discharge potential)**: This factor helps in understanding the extent of

<table>
<thead>
<tr>
<th>Factors</th>
<th>Degree of Importance (hypothesis)</th>
<th>Availability of Data</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainfall</td>
<td>Medium</td>
<td>High</td>
<td>Taken as a factor of the study</td>
</tr>
<tr>
<td>Natural Water Seepage</td>
<td>Medium</td>
<td>High</td>
<td>Not included in the study as Bengaluruhas uniform soil structure— Granite gneiss</td>
</tr>
<tr>
<td>Evapotranspiration</td>
<td>Low</td>
<td>Low</td>
<td>Not included in the study as the degree of importance and the availability of data is low</td>
</tr>
<tr>
<td>Land Use/Land cover</td>
<td>Medium</td>
<td>Medium</td>
<td>Included in the study to find the basic relationship</td>
</tr>
<tr>
<td>Artificial Water Seepage</td>
<td>Low</td>
<td>Low</td>
<td>Has minimal coverage of rain water harvesting and hence this factor is not considered to find effect of GW potential in the region Not considered for the analysis and being corrected by BWSSB incrementally</td>
</tr>
</tbody>
</table>

Table 3: Parameters related to ground water (GW) recharge and its relevance for Bengaluru
Factors affecting the exploitation of GW to determine whether the ground water inflow is better to compensate extraction. In an ideal case, both have to match over a period of time thus ensuring that this natural resource is sustainably managed. The table below gives the relevance of factors affecting recharge potential (Table 4).

- **Ground Water wells' statistics:** Bengaluru has huge number of wells being dug which is not controlled or managed in a centralized manner. According to BWSSB, Bengaluru urban region have 3,19,331 bore wells among which 7415 wells are maintained by BWSSB. Private parties also dig wells to cater to their water needs on a continuous basis. Private entrepreneurs supply ground water to other customers through the wells they have dug for commercial purpose. There are no official statistics on the exact number of wells. However, the following graph gives the approximate growth of number of wells in Bengaluru. According to the data availed from BWSSB, the total no of wells for urban Bengaluru is considered as 3,19,331 as of July 2016. Geometric progression is assumed to extrapolate the number of wells for a period of one month. (Fig. 2)

Number of wells is an indicator of the extend of ground water

<table>
<thead>
<tr>
<th>Factors</th>
<th>Degree of Importance (hypothesis)</th>
<th>Availability of Data Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anthropogenic activities</td>
<td>High</td>
<td>Medium but not reliable Demand from Population characteristics including population density, population growth % over a period and demographic and economic profile of the population For the ease of analysis and the availability of granular data, only population density (ward wise) is taken into consideration in the analysis</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>Low Alternate GW uses including GW usage for irrigation</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>Medium Availability of alternate sources of supply represented by % coverage of population by BWSSB networks As Bengaluru have 2 sources of supply (a) Surface Water distribution by BWSSB (b) GW, the % coverage of Surface water from BWSSB is considered for the analysis</td>
</tr>
<tr>
<td>Aquifers</td>
<td>High</td>
<td>Low Precise mapping of aquifers compared against the GW extraction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Although an important factor for consideration, un availability of aquifers' data in comparison with consumption data, make this factor out of consideration</td>
</tr>
<tr>
<td>Water Table movements</td>
<td>Medium</td>
<td>Medium The GIS mapping of GW table movements for the city of Bengaluru derived from the Water Level movements (seasonal) for the year 2010 and 2015 of wells maintained by CGWB Taken into consideration to find out the water table / level movements for the city of Bengaluru. This will determine the general water table movements helping to find out the critical areas of ground Water</td>
</tr>
</tbody>
</table>
Fig. 2: Progression of number of wells (Source BWSSB primary data)

Fig. 3: Correlation Graph-Region wise
usage which is evident from the Fig- 2. The above figure shows south faces the highest progression in digging wells and the least is identified in central region.

**Correlation of population & BWSSB coverage to no of wells:** The well statistics of different divisions and sub divisions are analysed with population, population density and BWSSB, coverage to find out the correlations in Fig .3.

Thus, it can be concluded that there is no uniform correlation between population density and well density across Bengaluru. South and west which are the older residential areas have no correlation of well density (exploitation indicator) to the population, which reveals that number of wells is just an indication of number of households and not really an indicator of the population density of the region. However, there is a direct correlation between absolute population and well density in areas of central, south, south east, south west and west which are the older developed regions. However, the other regions which are north, north east, north west and east show no major correlation between absolute population and well density (Fig .3).

**Ground water potential analysis for Bengaluru using water table movements:** Water table is the level below the ground which is saturated with water. The upper surface of the zone of saturation is called the water table which separates the zone of saturation from the overlying zone of aeration. During rainy days water penetrates to the underground surface and passes through the voids among rocks and joins water table. This ground water moves through these voids which are interconnected below the surface (Santhosh and Rajeswari, 2007). Water table movements are dependent on various factors viz; soil topography, porosity (which is the amount of water soil can hold at a time) of the soil, permeability of the soil, gravity, recharge and discharge, cohesion of water molecules, transpiration pull of plants which absorbs water etc. Ground water movement can be assessed by deriving the direction of flow of net water level contours for an area (Subramani and Kaliappan,2016)

Water table movement is an alternate way to map the ground water potential and identify the critical areas in Bengaluru. The methodology used here is to assess the ground water level of the observatory wells maintained by CGWB and DMG using GIS technique to identify the water level fluctuations. The water level is contoured using GIS to create equipotential fields. However, the following assumptions are made for constructing the GW potential for the region (Jain and Kumar, 2012)

- The aquifer is homogeneous.
- The aquifer is fully saturated.
- The aquifer is isotropic.
- There is no change in the potential field with time.
- The soil and water are incompressible.
- Flow is laminar, and Darcy’s law is valid.
- All boundary conditions are known.

Remote sensing data combined with GIS (Geographic Information System) is useful for the delineation of ground water potential of any area. Due to the gravitational pull, ground water moves down to earth. Meanwhile it moves up due to the flow from high pressure areas to low pressure regions. (Subin et al, 2012).

Using GIS technology, the maps of the jurisdiction of BBMP, jurisdiction of BWSSB and jurisdiction of CGWB are overlaid to come up with a composite map (Fig 4). On this map, the well positions (co-ordinates) are marked using longitude and latitude using GIS technology. The attribute details of the wells which include the name and the depth to water level are marked in the map (Fig. 5).

Water table movement analysis is done to assess the ground water potential for the city. The steps involved in the process are as follows:

- Grouping the wells by contouring the depth to water levels to get an idea about the variation in flow of ground water.
- Attempt is made to visualize the water table movements for the city of Bengaluru urban region using GIS techniques incorporating season wise depth to water level data for the years 2010-2015 from various departments (CGWB and DMG)

The ground water observatory wells’ resultant water level is mapped using GIS technologies to find out the water table movements for the period 2010 (Fig.6) to 2015 (Fig.7)
Fig. 4: Composite Map showing all the boundaries of BBMP, BWSSB and CGWB

Fig. 5: Location of observatory wells with water depth level
The following conclusions can be derived from the seasonal variation of ground water levels. Water table movements (2010 and 2015) are done to determine the critical areas with respect to ground water and the direction of ground water movements in Bengaluru and show the following trends.

- Ground water level is showing depletion throughout the study area in 2015 compared to 2010. There were very few safe zones in ground water by 2015 in the city.
- There is minimum seasonal variation between 2010 and 2015.
- North and north west have already moved to be highly critical area w.r.t ground water. Certain pockets of east are also showing ground water criticality.
- Further it is observed that seasonal variation is having minimal influence on ground water fluctuation in the study area.

The critical areas for ground water in the city are analysed by the level of ground water as follows using GIS techniques for the period 2010 and 2015. Ground water level is showing depletion throughout the study area (Fig.8).
CONCLUSION

For effective management of ground water, an understanding of the relevant factors which determine the inflow (recharge potential) and outflow (extraction potential) of ground water specific to the city is essential. Recharge potential of ground water of the city mainly relies on rainfall whereas the discharge potential depends on factors which include agriculture, irrigation, population density etc. However, population density is considered as the major factor affecting ground water level as Bengaluru is an urban area.

The study incorporates a ground water well progression analysis due to lack of official statistics of number of wells. It shows south division has high digging of wells in comparison with central division which shows the least number of wells.

Multivariate analysis is attempted to draw the correlation between well density, population density and absolute population. The result shows no uniform correlation between well density and population density across Bengaluru. However, there is a direct correlation between well density and absolute population. The result indicates that number of wells is just an indication of number of households and not really an indicator of the population density of the region.

Water table movement analysis was also done using GIS technique for the years 2010 and 2015 to delineate the critical areas w.r.t ground water in Bengaluru and the progression in criticality over a period of five years as well. The analysis shows there is minimal seasonal variation in ground water level both in 2010 and 2015. However south west, north west and pockets of east show depletion in ground water level in 2010.

**Fig.7: Seasonal Variation of Ground Water in 2015**
Fig. 8: Progression of critical areas for ground water (2010-2015)
Ground water level shows a depletion in 2015 compared to 2010 throughout the study area leaves very few safer zones for the year 2015. North, north west and pockets of east are moving to highly critical zones which needs to be addressed carefully to avoid serious difficulty in meeting water needs among the society in future.

REFERENCES

1. Bengaluru Revised Master Plan, 2031. (RMP 2031) Database/Information for preparation of Revised Master Plan 2031 for Bengaluru, Bangalore Development Authority
13. Suresh, T. S. (2001). Department of Geology, Bangalore University, Bangalore 560056, India; An urban water scenario: a case study of the Bangalore metropolis, Karnataka, India; Regional Management of Water Resources; Proceedings of a symposium held during the six IAHS scientific assembly at Maastricht; The Netherlands, IAHS publication, no.268


http://jebsharidwar.org/