Journal of Environment and Earth Science
ISSN 2224-3216 (Paper) ISSN 2225-0948 (Online)
Vol.7, No.2, 2017

Groundwater Flow Direction, Recharge and Discharge Zones Identification in Lower Gidabo Catchment, Rift Valley Basin, Ethiopia

Genet Mathewos Messene
Addis Ababa Construction and Housing Development office; Design, Construction and Supervision Core Process, Addis Ababa, Ethiopia

Abstract

Groundwater is occurring in different geologic formations and topographic features, those factors mostly control the distribution and development of groundwater. In this study, groundwater potential of the catchment was investigated with exploring groundwater flow direction, recharge and discharge zones. The study embattled to understand comprehensive aspects of groundwater potential and hydrogeological features of the catchment. Surfer 8 and Arc GIS 9.3 programs were used for the study to realize groundwater flow direction, recharge and discharge zones. Arc GIS was too used for geo referencing and mapping of the catchment. Groundwater flow direction of the catchment was identified by using groundwater level maps. According to groundwater flow lines and contour maps, groundwater flows from eastern highland parts of the catchment towards the plain areas in the western direction. As per the result perceived, the major recharge of groundwater occurs in Eastern and Northeastern highlands of the catchment, which is said to be recharging zone. However, the area situated in Western and Northwestern parts of the catchment are discharge zones. Therefore, dumpsites could be sited out of southeastern, southern and northeastern parts of the catchment to minimize groundwater contamination. As well, hand dug well for potable water supply could not be placed in Southeastern and eastern escarpment of the catchment.

Keyword: Groundwater recharge and discharge zone, Lower Gidabo catchment, flow direction; Surfer and Geographic Information system

1. INTRODUCTION

Groundwater is one of the most dynamic natural resource, which enriches human health, economic development and ecological diversities. Groundwater is a vital natural resource for the reliable and economic provision of potable water supply in both urban and rural settlement. The source plays an ultimate role in human well-beings, aquatic and terrestrial ecosystems. At present, groundwater contributes around 34 per cent of the total annual water supply and is an important fresh water resource in the world. Assessment of groundwater resource is important for sustainable management and development of groundwater systems (Dar *et al*., 2010 and Magesh *et al*., 2011b).

Groundwater recharge is one of the more difficult components of the hydrological cycle to estimate, but it is gradually imperative for future economic development. Knowledge of both groundwater recharge and discharge is essential for effective management of groundwater resources (Crosbie *et al*., 2009). The long term management of groundwater resources requires careful estimation of groundwater balance components including recharge and discharge. Traditionally, the setting of upper limits for groundwater allocations has been on the basis of recharge, but recently, surface and groundwater linkage has required the impact of pumping upon groundwater discharge is considered when setting water allocations. It has been argued that, the size of a groundwater resource is determined by the amount of captured discharge and induced recharge, rather than the rate of natural recharge (Crosbie *et al*., 2009 cited in Theis, 1940 and Bredehoeft, 2007). Absence of information regarding groundwater flow direction in the catchment lacks for future proper land use planning. Thus, determination of groundwater flow direction and flow patterns are necessary to ensure the land use activities in the recharge area that will not pose threat to the quality of water (Freeze and Cherry, 2002). Likewise, identifying groundwater recharge and discharge zones through the catchment is critical for implementing effective strategies for salinity mitigation, surface water and groundwater resource management and ecosystem protection. Mapping of recharge and discharge area is integral to managing water resources and understanding salinization processes (Tweed *et al*., 2007).

Ethiopia is being a third world country, which is not excluded the nations suffering from the negative socio-economic outcomes of potable water shortage. It is certainly in the progressive fulfillment of its most urgent water needs. The percentage of the people who had access to clean and safe water is very minimal. The population has no adequate clean water supply partly they lacks efficient, equitable and optimum utilization of water for significant socio-economic development in a sustainable basis (MoWIE, 2007).

Lower Gidabo catchment in Sidama and Gedeo Zones comprised in the six woredas has a potential risk of adequate water supply for irrigation, domestic and small industries. They are affected by a recurrent drought, poor water supply and sanitation services; due to this, several socio-economic activities and the well-being of the people are uncertain. Some of the community has no safe drinking water access at acceptable distance. Some parts of the community mainly in the rural settlement use untreated surface water for domestic and drinking purpose, yet water scarcity problems are predominant. It is jeopardy to human health associated with consumption of polluted water. It is known that water is basic for socio-economic development of the people whose income is primarily dependent on agriculture. Most of the residents living in the area are rural people whose livelihood is mainly dependent on agriculture with poor water supply and sanitation services. The study area is affected by flooding, erosion and sedimentation problems.

The gap of understanding groundwater potential is one of the factor in planning water supply from groundwater resources. Therefore, assessment of groundwater potential in the study area is the main approach for improving the use of groundwater resource. It was addressed to understand groundwater flow direction; identifying groundwater recharge and discharge zones. The results of this study will significantly fill the gap of understanding groundwater perspectives in the catchment. It is important to provide vital information for sustainable groundwater development and management.

2. MATERIALS AND METHODS

2.1 Description of the study area

The study was conducted in Lower Gidabo catchment, Abaya Chamo Sub-basin, southern, Ethiopia. It is located in Sidama and Gedeo zones, which encompasses in the six Woredas namely; Aleta wendo, Aleta Cuko, Wenago, Dilla, Dara and Bule woreda. The catchment lies between 6°39’N to 6°12’N and 38°14’E to 38°21’E covering an area about 1047.5 km^2. The altitude of the catchment ranges from 1170 to 3200 m AMSL. The catchment is undulating and ranges from low relief characterized by high fault cliffs, steep hills and low flat land close to Lake Abaya to high relief. The geology of the catchment is characterized in seven geologic formations Viz. Trachytic basalt and Rhyolit (19.3%), Terrace gravel deposits (38.4%), Nazareth group Alkaline and per alkaline stratoid silicics (15.8%), Dino Formation (14.8%), Pyroclastic fall deposit (1.1%), Transitional mildy alkaline (9.4%) and Bofa Basalts (1.3%). The climate of the study area are ranges from Woina Dega to Dega. It is normally characterized by subtropical Woina Dega on the rift floor and temperate to humid Dega climatic zones on the escarpment and adjacent highlands. The mean annual rainfall and temperature is 1,100 mm and 20°C respectively.

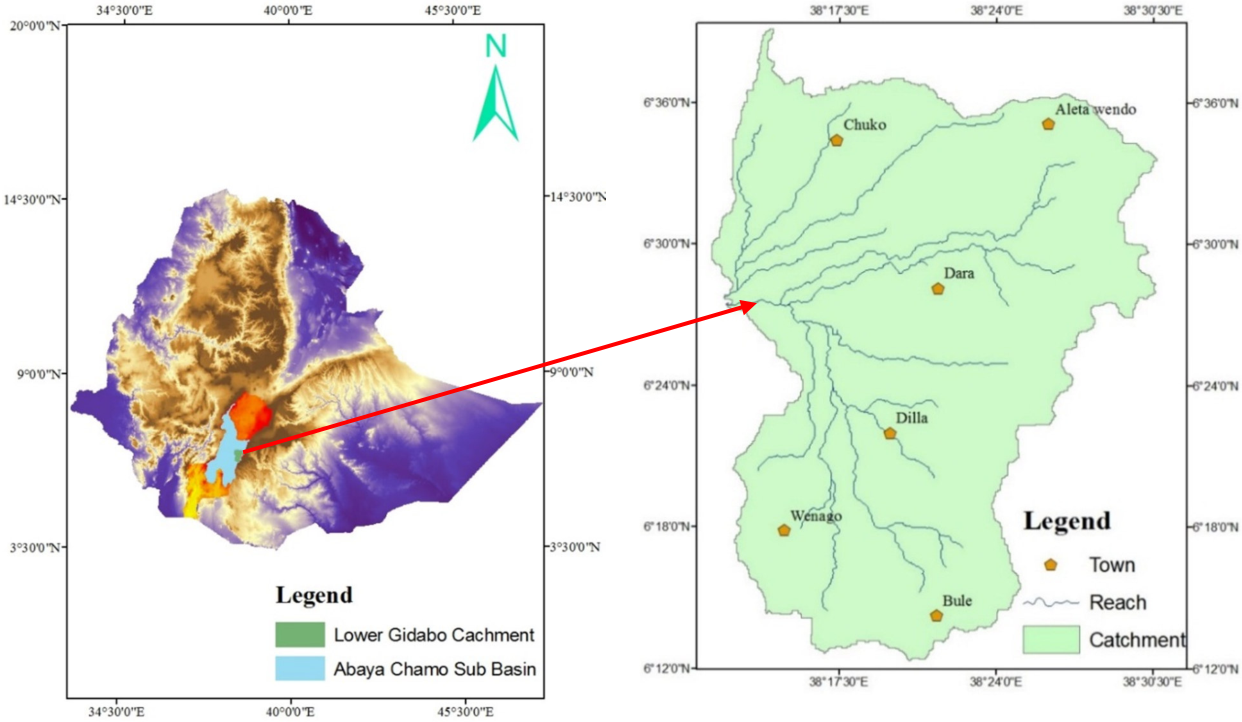

Figure 1: Location map of the study area

2.1.1 Drainage

Lower Gidabo catchment consists of main Gidabo River and some tributaries which flow to the main River in western direction. The catchment stream network shows dendritic drainage pattern in the upstream areas and sub-parallel patterns in the downstream sections. In a dendritic system, there are many contributing streams which are joining together to the tributaries of the main river. Eastern part of the catchment is topographically higher while south western part is lower near Lake Abaya (Figure 2).

2.1.3 Slope of the area

Slope map of the study area was generated from 30*30m DEM resolution using spatial analyst tool in Arc GIS 9.3. As per Wagener *et al* (2007) slope classification, the slopes of the catchment were categorized in four classes. It varies from 0 to 91per cent viz. 0-2 (gentle), 2-8 (moderate), 8-36 (steep) and greater than 36 per cent (very steep) slopes. The eastern parts of the catchment are dominantly covered by steep and very steep slopes. However, the upper and western parts of the catchment are relatively considered as gentle slopes (Figure 3).

2.1.4 Land use-Land cover

According to Habtamu and Rapprich (2014) the vegetation cover in the study area varies from east to west. It depends on the altitude and soil type across the sub catchment. Major crops grown in the upper parts of the sub catchment are coffee, enset, maize and teff. However, in the lower and middle parts of the catchment, livestock production is the main activity of the community. The catchment area is covered by 73.3% of intensively cultivated land, 9.5% moderately cultivated land, 14% shrub land, 1.7% marsh land and 0.16% forest (Figure 4).

2.1.5 Soils

The major soil units in the catchment are categorized as chromic luvisols (7.36%), Eutric Leptosols (4.73%), Eutric Vertisols (23.5%), Humic Nitisols and Lithic Leptosols (64.2%) (Figure 5). It comprised the major soil texture of Sandy loam, Loam, Clay, Sandy loam and Loam.

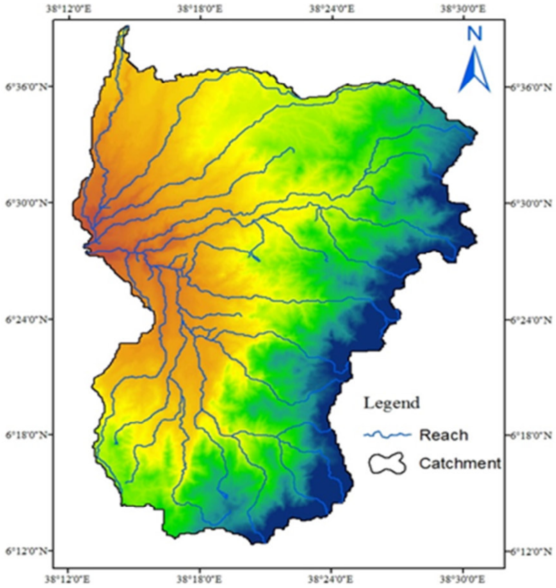

Figure: 2 Drainage map of Lower Gidabo Catchment

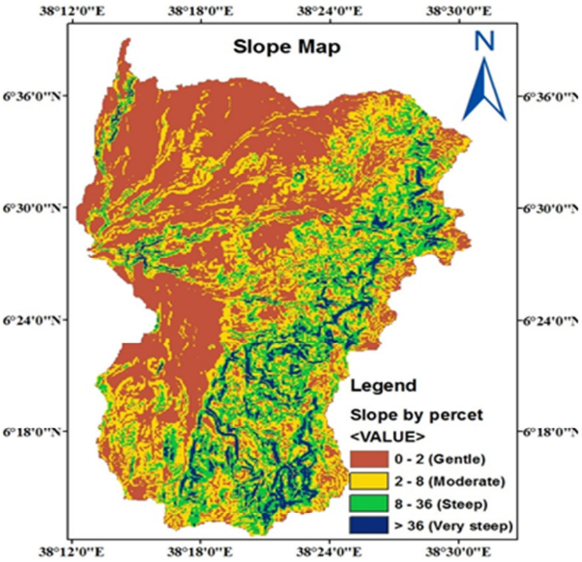

Figure: 3 Slop map of Lower Gidabo catchment

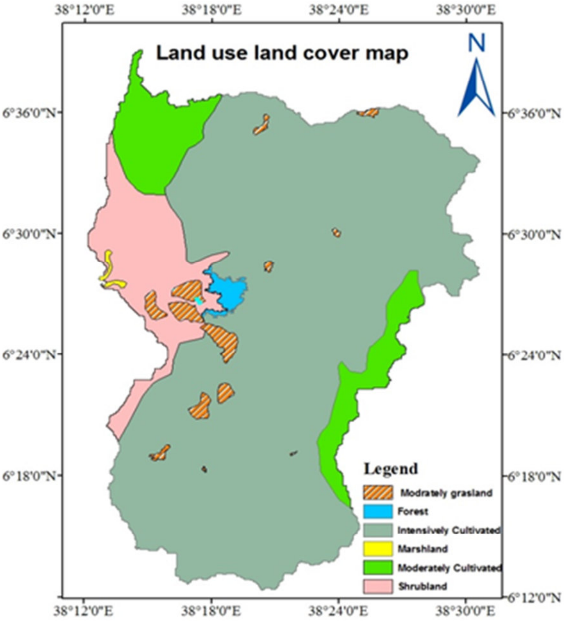

Figure: 4 Land use Land cover map (EMA, 2006).

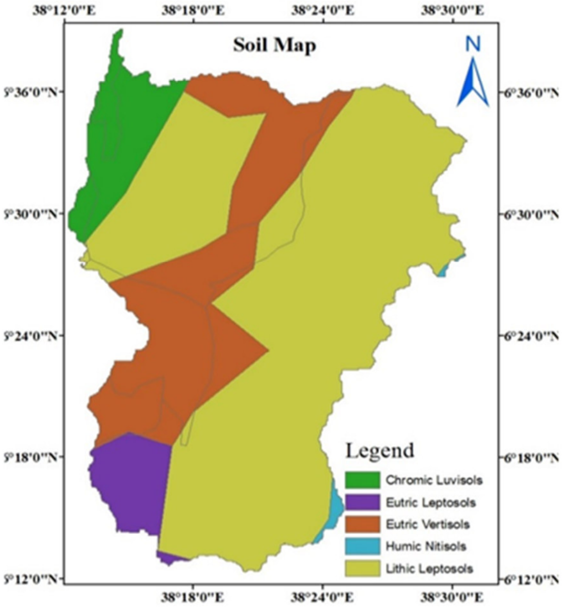

Figure: 5 Soil map of Lower Gidabo Catchment

2.2 Methods

2.2.1 Data sources, analysis and interpretation

The data were collected from secondary sources from Minister of Water, Irrigation and Energy, Ethiopian Mapping Agency, South Water Works Construction Enterprise and Sidama Zone Water, Mine and Energy Department. The data used in the study comprises; land use, geologic and soil data, completion reports of pump test boreholes data, geologic well log data, features of boreholes and hand dug wells, topographic map at the scale of 1: 50000.

The methods employed to acquire efficient information for investigating groundwater flow direction, recharge and discharge zone of the study area such as; generation of thematic maps to present drainage patterns of the catchment, slope, soil, geologic formation, developing groundwater flow direction, recharge and discharge areas were analyzed using Global mapper 12, Arc GIS 9.3 and Surfer 8 programs.

2.2.1.1 Mapping of groundwater flow direction

The significance in advance of groundwater flow direction was analyzed using Arc GIS 9.3 and Surfer 8 program. Surfer was developed to translate the XYZ data into clear surface and contour map. The three D (3D) map generated with Surfer is known for their clarity, color and accuracy (ECUC, 2001). To determine the flow direction of groundwater in the study area, a contour map of the catchment was generated using 40 XYZ data of boreholes and hand dug wells. The flow lines and equipotential lines (i.e. groundwater contours) were digitized by Arc GIS 9.3 software to create the shape files of features such as water wells and Rivers.

2.2.1.2 Groundwater recharge and discharge area identification

In order to prepare sound land-use planning and management approach, analysis of groundwater flow system connecting recharge and discharge areas is vital. The recharge and discharging zone of the catchment were identified with the help of Surfer 8 program, Arc GIS 9.3 and integration of thematic map of the catchment. The water table contour map was done using Surfer 8 program. Based on the groundwater flow direction in a contour map, the convergence and divergence zone of the catchment were identified. A water table contour map was used to identify groundwater recharge and discharge areas. The flow line on a flow net tends to diverge from recharge areas and converges towards to discharge areas (Fetter, 2001).

Groundwater recharge, discharge and intermediate zones of the catchment were mapped based on different indicators such as; topography, groundwater flow pattern and static groundwater levels (Afewerk, 2011 and Toth 1963, cited in Fetter, 1994). Those have contributed for the demarcation of the recharge, transitional and discharge zones. Among these indicators, topographic elevation is the simplest (Freeze and Cherry, 1979). Topography is a major factor which has to be considered for delineating the recharge and discharge zone; high land areas are an indicator of recharge areas. The divergence and convergence of vector flow lines is an indicator of the recharge and discharge areas respectively in general. A water table contour map was also used to locate groundwater recharge and discharge areas (Fetter, 2001).

3. RESULT AND DISCUSSIONS

3.1 Groundwater flow direction

Water table maps were plotted to determine horizontal groundwater flow directions in the catchment. The two dimensional contour map and 3D map presented below show the flow directions (Figure 6 and 7), all reveals the same trend. In two dimensional groundwater contour map abrupt change in flow direction is observed in convergence and divergence of the flow lines. However, the three dimensional map provides a visible picture and displays the controlling factors which affects the flow pattern.

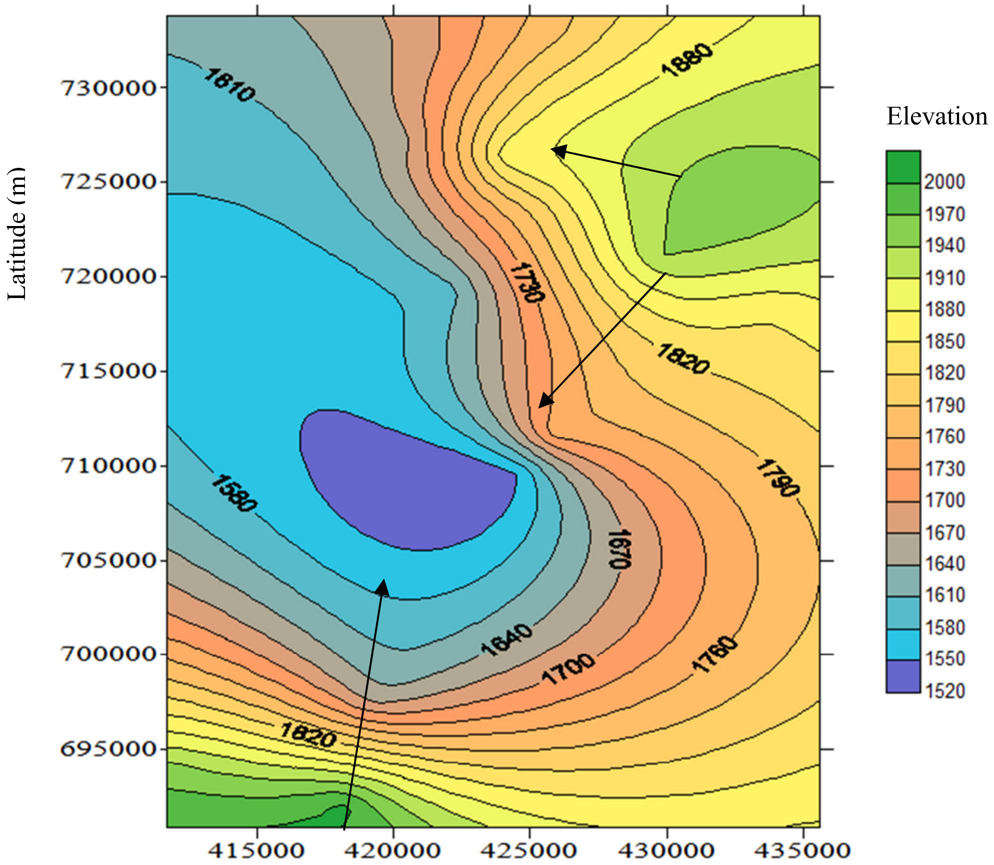

Figure 6: Groundwater contour map of Lower Gidabo catchment in two

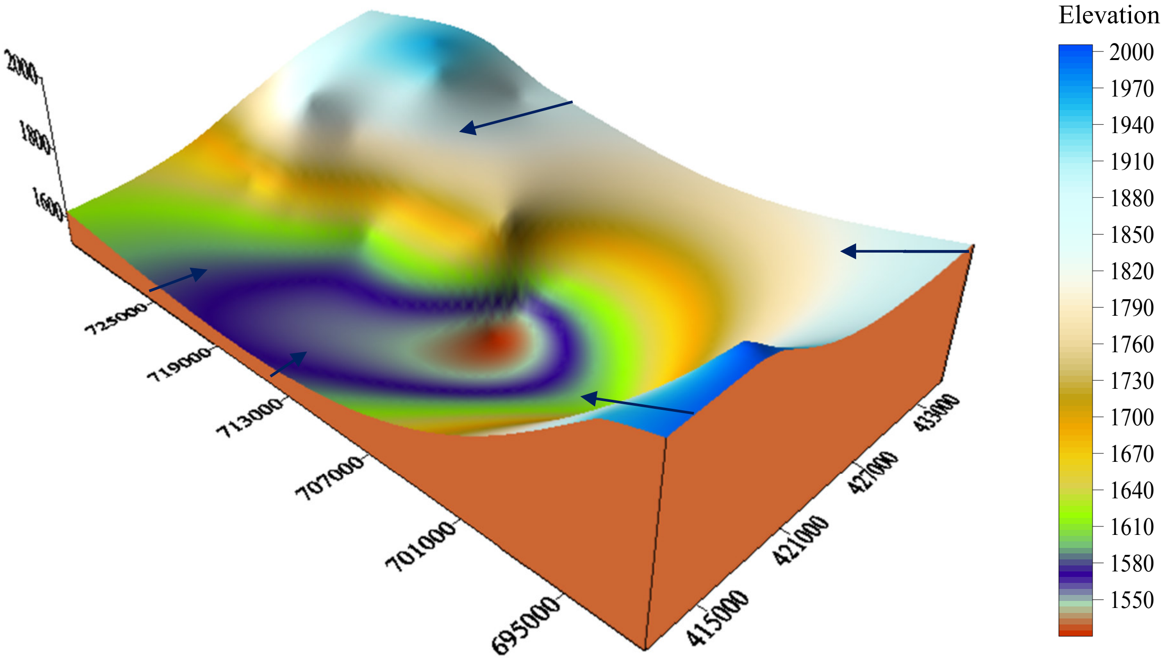

Figure: 7 Groundwater contour map of Lower Gidabo catchment in three dimension

The water table elevation in the catchment along the Southwestern escarpments of the catchment is defined by 2000 m AMSL; however the lowest water table elevation is about 1520 m in western Dilla. According to Julius and Merrious (2010, cited in Buddemerier and Schloss, 2000) groundwater flows from the highest contour elevation to the lowest in the direction perpendicular to the contour line. The contour map revealed that groundwater flows downward from the South in a higher hydraulic head towards to West located within the location close to Dilla. Likewise, groundwater flows from East northern towards Northwestern direction of the catchment (Figure 6). It was realized by employing the idea that groundwater flows from topographically higher elevation to lower elevation. The main sources of groundwater pollution were leachates from dumpsites and the wellbeing of inhabitants, thus, based on the groundwater flow pattern western parts of the catchment might be stand at risk if leachates are allowed to connect with groundwater.

3.2 Groundwater recharge and discharge zone identification

Groundwater is discharged from springs in highland areas mainly around Bule, estern Aleta Wendo, southeastern Wenago; and is originated in low land areas. Discharge in natural from groundwater system is from the flow of water into Rivers, wetlands and springs and evaporation from upper parts of capillary fringes where groundwater is close to the surface. This situation is likely suited in the low lands of the catchment area where groundwater level is close to the surface. Figure 8 and 9 shows groundwater recharge and discharge areas of the catchment.

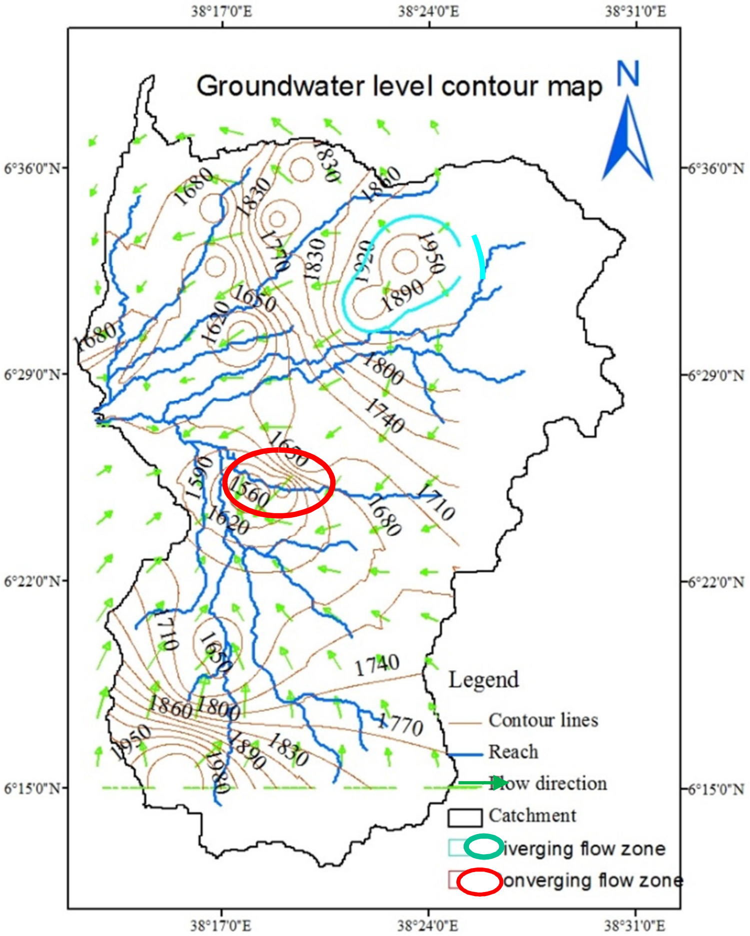

Figure: 8 Groundwater level contour lines, converging and diverging flow zones

Recharge to the aquifer varies in different locations due to variation in geology, slope, hydraulic connectivity, land use, morphologic variations. As can be seen in Figure 8, the diverging groundwater flow lines are suited in north eastern highlands towards western part of the study area of discharging zones. However, recharging zone is located in the eastern plateaus of the catchment area. The major recharge occurs in the Easter and Northeastern highlands of the catchment; where annual rainfall and slope is high. Rapid infiltration occurs in areas covered by fractured volcanic and a lesser extent in sedimentary rocks and thick permeable soils in somewhat dry lands. Due to the fact that, the area located in western and northwestern part of the catchment are discharge areas like in northern Wenago; eastern part of Dilla and Chuko.

The slope class of the catchment varies from 0 to 91 per cent categorized in four classes viz. 0-2 (gentle), 2-8 (moderate), 8-36 (steep) and greater than 36 percent (very steep) slopes (Figure 3). Eastern and southeastern parts of the catchment area have higher slope value; which are dominantly steep slope, it resulted greater runoff and thus lesser groundwater discharge. However, western and northwestern parts of the catchment have gentle slopes, which is considered as lesser runoff; hence groundwater recharge is lesser (Figure 8). Therefore, with regard to the slopes of the catchment area, upper parts of the catchment are considered as high groundwater potential zone. Whereas, the slope of the lower catchment area (eastern and southeastern part) is greater than 13%, thus the surface runoff is high allowing less time for rainwater to percolate, which is considered to be poor groundwater potential zone.

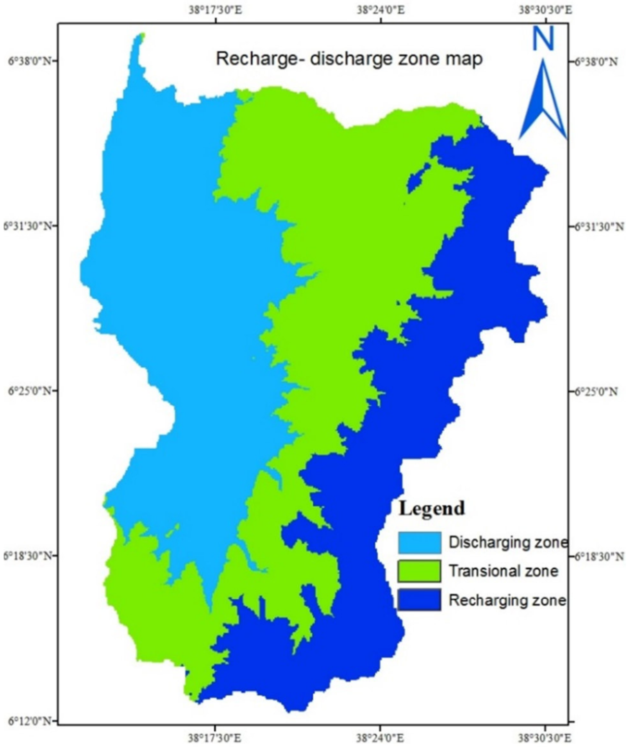

Figure: 9 Groundwater recharge, discharge and transition zones

4.CONCLUSION AND RECOMMENDATIONS

Groundwater is driven by lateral variation in topography in water table or phreatic aquifers. The cause of local relief in topography is high for groundwater flow. Due to pronounced local relief, various condition of groundwater flow in local and intermediate flow systems possibly exists. In the study area, the flow system generally follows due to topographic variation. It is important to determine the position of water level and flow direction in which groundwater moves, because many water related projects and constructions are highly influenced by groundwater flow system. The results of this study are significant in filling the gap of understanding groundwater perspectives. As per the results, Trachytic basalt and Rhyolites are the predominant hydrogeological units in the study area. Based on the contour map and groundwater flow lines, groundwater generally flows from east to west direction. It is affected by local flow systems observed in the locality of elevated hills, central parts and margins of the catchment. The plot of stream networks of the catchment and contours of hydraulic head revealed that, the catchment typically gain water in western and loses in the eastern part of the catchment. With regard to the groundwater flow direction, discharging and recharging zones, low relief areas along western parts of the catchment are characterized by good groundwater yields. Northern and eastern parts of the catchment have high amounts of recharge in high plateau areas. Hence, in order to minimize groundwater contamination from dumpsites mainly in western parts of the catchment, dumpsites should not be sited in Southeastern, southern and northeastern parts of the catchment. Eastern and upper part of the catchment are constituted trace gravel deposit, trachytic basalt and rhyolite and transitional mildy alkaline, thus taking direct recharge is important. Likewise, hand dug well for potable water should not be cited in Southeastern and eastern escarpment of the catchment, because the area is characterized with steep and very steep slope.

5.REFERENCES

Afework, D. (2011). Groundwater Potential Evaluation And Flow Dynamics of Hormat-Golina River Catchment, Kobo Valley, Northern Ethiopia, Addis Ababa University.

Buddermeier, R.W. and J.A. Schloss. (2000). Groundwater Storage and Flow. Retrived from http://www.kgs. Ukans.edu/Hight plains/atlas//apgengw.htm.

Bredehoeft, J. (2007). It is the discharge. Groundwater 45 (5). Wiley-Blackwell, 523-523.

Crosbie, R. S., McCallum, J. L. and Harrington, G. A. (2009). Estimation of groundwater recharge and discharge across northern Australia 18th World IMACS / MODSIM Congress, Cairns, Australia, 3053-3059, retrieved from HYPERLINK "http://mssanz.org.au/modsim09" http://mssanz.org.au/modsim09 .

Dar, I.A., Sankar, K., Dar, M.A. (2010) Deciphering groundwater potential zones in hard rock terrain using geospatial technology. Enviromental monitoring and assessment 173, 597-610.

Ethiopian Mapping Authority (EMA). (1988). National atlas of Ethiopian. Addis Ababa, Ethiopia.

Fetter, C.W. (1994). Applied Hydrogeology, 3rd ed. Macmillan College Publishing, Inc., NewYork, 616 .

Fetter, C.W. (2001). Applied hydrology. Prentice-Hall, inc. upper Saddle River, NewJersey.

Freeze R.A. and Cherry, J.A. (2002). Groundwater. Prentice-Hall: Englewood Cliffs: Englewood Cliffs, NY. 604.

Freeze, R.A. and Cherry, J.A. (1979). Groundwater. Prentice-Hall, Englewood Cliffs, New Jersey.

Habtamu, E. and Rapprich, V. (2014). Geological hazards and engineering geology maps of Dilla. Explanatory notes, Czech Republic, 1st ed., p 37-6, retrived on http://www.kgs.ku.edu/HighPlains/atlas/apgengw.htm.

Magesh, N.S, Chandrasekar, N. Vetha Roy, D. (2011b). Spatial analysis of trace element contamination in sediments of Tamiraparani estuary, southeast coast of India, Coastal and Shelf Science 92, 618-628.

Ministry of Water, Irrigation and Energy (MoWIE). (2007). Overview of Ethiopia's ground water resources. Addis Ababa, Ethiopia

Theis, C.V. (1940). The source of water derived from wells: Essential factors controlling the response of an aquifer to development. Civil Engineering 10 (5), 277-280.

Toth, J. (1963). A theoretical analysis of groundwater flow in small drainage basins. Journal of geophysical research, 68(16), 4795-4812.

Tweed, S. O., Leblanc, M., Webb, J. A. and Lubczynski, M. W. (2007). Remote sensing and GIS for mapping groundwater recharge and discharge areas in salinity prone catchments, southeastern Australia. Journal of Hydrogeology.

Wagener, T., Sivapalan, M., Troch, P., & Woods, R. (2007). Catchment classification and hydrologic similarity. Geography Compass, 1(4), 901-931.