ASSESSMENT OF GROUND WATER OCCURRENCE USING BY GEOLOGICAL, GEOMORPHOLOGICAL AND GEOSPATIAL METHODS : A Case Study of East Wollega Zone, Ethiopia

Original Research Article

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ABSTRACT

The study area is located in western Ethiopia of Oromia regional state on East wollega zone, at a distance of 332 km from Addis Ababa capital city of Ethiopia. It is bounded between 36^{0} 30'00" to 36^{0} 45'00''longitude and 9^{0} 05'00'' to 9^{0} 15'00'' latitude. The area is covered by exposure of volcanic rock and some of quaternary sedimentary rock. Rainfall and snow are a natural source of ground water by percolating through soil zone and unsaturated material. The main objectives of this study are to evaluate the role of geological structures, geomorphological features and surface design on the occurrence of ground water flow. The methodology used to study the area is pre-, and post- during field work by using different geological, geomorphological methods to determine the geomorphic feature and geological structures such as, lineaments and tectonic structure (joint, fracture and dykes) and geospatial method using (Arc GIS software) to determine DEM (Digital Elevation Model), slope and aspects of study area. The majority land of the study area is covered by volcanic rock units having dendrite drainage patterns, dome shape and flat land forms. The fractured basalt and high topography are suitable for ground water percolation; whereas the low land and altered basalt are essential for discharging of the ground water.

Keywords:

Dendrite,
Lineaments,
Percolation,
Topography,
Unsaturated,
Volcanic rocks,

I. BACKGROUND

Ground water is one of the essential resources to life, which located beneath the earth's surface in soil and percolated due to pore space and fracture of the rock formation. Surface water bodies help for the recharge of ground water. Precipitation in the form of rain falls to the stream on the land surface as over land flow to tributary channel and in the subsurface as inter flow or lateral subsurface flow and base flow by following the infiltration into the ground. A portion of the infiltrated water inters the ground water or aquifer system by passing through the vadose zone and it exits in the atmosphere, surface water in the plant (D. K. Todd 2005). This process is called ground water recharge or ground water flow. On the other hand ground water recharge means addition of water to the ground reservoir. The main objective of the study, to identify the geologic structures and geomorphology that affects the occurrence of ground water and the degree of inter connectivity of pore spaces.

Ground water is the water occurs in ground surface of soil, pore space fracture of rock formations and unstable quantity of water is yield from a unit of rock called aquifer (Fetter,2). The topographic features and general surface gradient, regional structure, porosity, permeability and special geological structure like; sink hole, alluvial fan, dykes, joint, lineaments, buried channel, weak zone and fractures and climatic condition have great role on the occurrence of ground water (Tamiru, A.2006).The rain fall that percolates below the ground surface passes through voids of rock, fracture and joints to reach water table. These voids are generally interconnected permitting the movement of ground water. The mode of occurrence of ground water largely depends on the topographic formation and geologic structure. Weathered layer, fracture and other structure are a source of ground water (Garg, 2007), With regard to the existence of water at different depth; the earth's crust can be divided into two zones. These are zone of rock flowage and zone of rock fracture. The depth of flowage is the zone in which the rock undergoes permanent deformation and is not well known, but it is generally estimated as many miles. The water estimated in this zone is known as internal water. The zone of rock fracture lies above the zone of rock flowage. Rock fracture can sub divided into two zones. One is zone of saturation, which is below the water table, another is unsaturated zone, which is above the water table (Garg, 2007). Ethiopia has abundant water resource potentials and the estimated amount of yearly ground water recharge of the country is about 2800mm3(millimeter cube) (Mowr,1998).

Description of the study area

The study area is located at western part of Oromia regional state at a distance of 332km from Addis Ababa. Geographically, the study area is bounded between $9^0 05'00"$ to $9^0 15'00"$N latitude and $36^0 30'00"$ to $36^0 45'00"$E longitude.

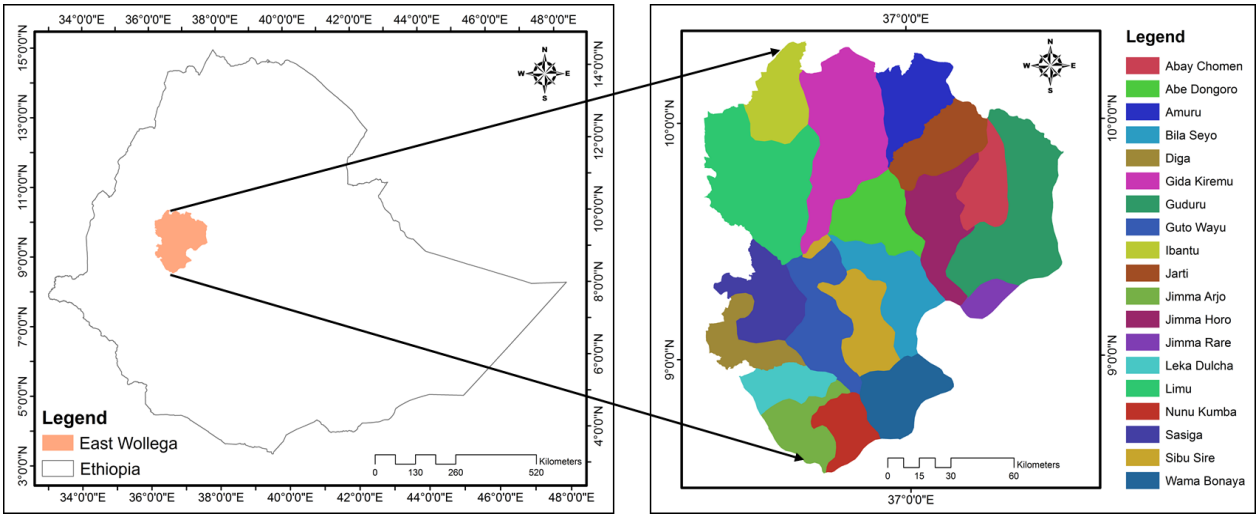

Figure – 1: Location map of the study area

Physiographic and drainage pattern

There are two major physiographic land forms of the study areas, lowland and highland. It is broadly divided between highland of 3207m and low land of 771m at mean sea level. The highland of the study area is characterized by mountain and mountainous chain, very thin soil, volcanic forms, weathered and fractured rock which is important for the percolation of rainy water and it is recharging of the study area. The lowland feature of the area has covered by thick soil layers, which is characterized by moisture content and altered basalt that facilitates for transmitting and holding of water. So, the low land area is used as discharging of ground water.

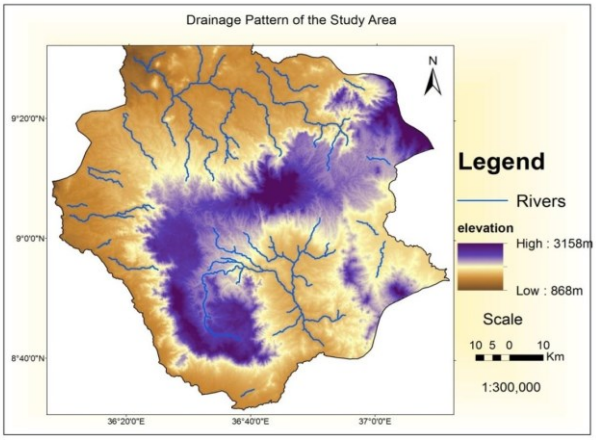

Figure -2 : Drainage pattern of the study area

The drainage pattern plays a great role for ground water recharge and slope stability. Its boundaries are marked by a ridge of highlands from which precipitation will drain to lowland to which ground water flows. Its boundary is called water shade which is the area of the land where all the water that is under it or drains of it goes to the main stream. The primary objective of the drainage basin morphology is to gather accurate measureable feature of stream net work and drainage basin. The drainage pattern types (dendritic, parallel, rectangular and circular), the drainage of the study area is typically dendritic form, which is essential for ground water occurrence, because these tributaries are the main source of recharge and pumped large amount of discharge. This pattern is associated to uniform litho logy, horizontal and gently dipping slope of strata and low relief.

The climate condition of the study area is bounded between two seasons. According to metrological record the main rainy season ranges from May to the beginning of September and the dry season ranges from December to April. The weather is cold during rainy season at highland and medium at low land, where as hot during dry season. The tempera is hot in winter season during day and cold during night time. The study area is found semi humid climate zone.

Table -1 .Mean monthly rain fall of the study area

YEAR	MONTHS												
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Octo	Nov	Dec	Annual
2011	43.4	8.4	55.8	84	266.6	414	251.1	337.9	786.0	80.6	57	15.5	199.98
2012	0.29	7.3	34.1	33	251.11	306	337.9	595. 2	303.8	96.2	69	15	130.016
2013	11.7	3.9	24.4	8.7	509.4	356.4	392.7	303.9	301.5	91.1	79.8	0	173.62
2014	0.6	4.6	116.6	148.9	396.8	435.6	360.2	279.8	460.2	209.6	31.4	0	203.69
2015	0.5	35	42.2	1.6	281	364.6	630.8	301.7	261.5	92.9	78.4	56.3	178.875
mean	11.3	10.38	54.62	55.24	340.98	375.3	334.5	363.5	368.4	114.0	63.1	17.36	177.245

Source; National Meteorological Agency Ethiopia

From the table number -1, the monthly rain fall of study area is high from May to September, between these months there is high amount of precipitation and percolation of water, because the area gets a maximum rainfall these months. So the ground water recharge is high due to high rain fall intensity between May to September.

Geology and Geomorphology of the study area

The metamorphic basement rocks of eastern wollega map is part of the Proterozoic rocks of the Western Ethiopian Shield, which is assumed to be the southern extension of the Arabian-Nubian Shield (.A.N S). Since late seventies, various authors (Kazmin et al, 1978, and Chewaka, 1 9 8 1 , A m e n t i , 1989) have studied the Proterozoic rocks of Western Ethiopia. The Eastern wollega area is indicated to be part of the eastern bounding gneiss. The sedimentary succession of the Abay Basin (west central Ethiopia) consists of lower sandstone (Adigrat sandstone), transitional beds (Abay beds or Gohatsion formation), Antallo limestone and upper sandstone (Ambaradam or DebreLibanos Formation). All the sedimentary formations decrease in thickness from east to west except the lower sandstone.

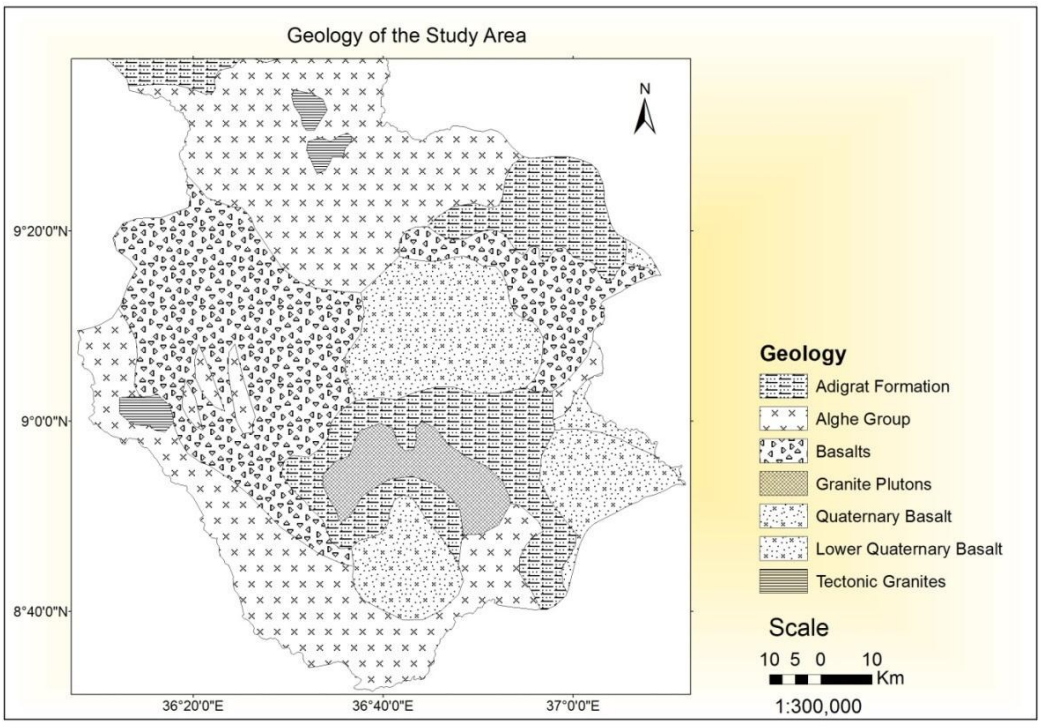

Figure-3 : Geological map of the study area

In figure -3, the Adigrat formation, tectonic granites and granite plutons are invisible in eastern wollega area but in the western direction they are rarely exposed within metamorphic rock, based on regional geologic mapping and field checking for completion have indicated the occurrence of three type of rock in eastern wollega map. They are; Precambrian basement rock, Paleozoic to Mesozoic rock and quaternary volcanic rock.

The local geology of the study area is covered by tertiary volcanic rocks bands show the vertical columnar jointing together with sub horizontal having an elevation of 2060m above sea level. This unit is characterized by fine granular rock, small crystal which is invisible by necked eye. It is moderately too high on the depth of water table. This rock unit mainly exposed around Kumsa moroda in Nekemte area. This basalt is characterized by large vesicles from where gas escaped out and used for percolation of precipitation to determine ground water potential. This unit is neither vesicular nor fractured. Its fine grained and compacted hardly. It has no porosity and no permeability. So, it prevents ground water percolation and no structures there on it. This litho logic unit is highly weathered and fractured. Due to this reason, it has void space to hold and transmit the water. So, it has high potential for the ground water occurrence.

Geologic structures are formed by the rock deformation at contraction and non-contractions are responsible for ground water occurrence. The deformation events leading to the deformation of distinct generation geologic structures are resulted from different tectonic forces acting on the rock. By studying and understanding the nature and inter relationships of these tectonic structures it was possible to determine deformation episodes. Therefore, placement of existing tectonic fabrics such as, foliation, lineation, folds, fractures others to deformation episodes gave the impression that different structures have developed.

Geomorphological Features and Land Form

The dominant geomorphologic features which have favored the development of potential aquifers and ground water occurrence are extents of drain age pattern, thickness of alluvial and Aeolian materials, topography and extent of structurally weak zone. The geomorphic features of the study area also control the sub-surface water flow direction, geochemical zones and gradient of aquifer. The majority land form of the study area is formed by volcanic activity which has mafic materials and low viscosity. The land form of the study area is dome shaped because low viscosity of mafic materials which is responsible for making the land form of East wollega to be flat shape. These help for to determine the recharge and discharge of the area.

Hydrogeology

The ground water present in all geologic formation is studied under hydro geology. Ground water storage of geologic formation depends on pore space exist in the rock, where fault, joint fracture, stratification and etc are there. Geomorphologic features also other factor to control the extent of ground water reservoir. The quantity of ground water in geologic formation depends on different parameter such as, distribution and infiltration area, hydraulic properties of aquifer and geology of the area. All of these property influences the local hydro geology of the study area. The duration and intensity of annual rain fall around the study area is so high and the fracture of the basalt which has columnar joints and other contact layer between the two litho logy serves as the conduct for the movement of ground water. The weathered layers (regolith), developed on intact volcanic and sedimentary rocks and fractured zone are an important source of ground water for the rural and urban water supply in the studied area. Normally the alluvium and volcanic rock units in the area lacks primary porosity which preserve ground water.

In volcanic rock; fractures, vesicles and inter flow sediments are the main features of ground water occurrence. From these factors; fractural structures are more dominant for recharge in the study area. The vesicular basalt has high primary and secondary porosity and hence high permeability for ground water movement and reserve. Springs are an important source of hydraulic information that occurs because hydraulic head in the aquifer system intersects the land surface.

II. MATERIALS AND METHODS

Methodology indicates the techniques of data collection analyze and interpretation APHA Standards methods (1992). This method is used to gather information about geology of the studied area including structures and geomorphology and their relationship with ground water occurrence. This include determination of whether the geologic structure has weak zone and fracture of not for infiltration of water into ground and clear observation of geomorphic features, porous and permeable part of litho logic unit, Singhal B.B.S Gupta, R.P,(1999).

This method is used to study the occurrence of ground water flow direction by collecting information about geologic structure such as extension of fracture and weak zone, orientation of geologic structure, topographic setting of the study area, estimating porosity and permeability rock unit and hydro logically the nature of the area such as, stream flow, spring ground water recharge and discharge and assessing the existing water source of the area. The collected data should be analyzed by comparing geologic structure and geomorphologic features from the field. This include analyzing how the geologic structure have affection on the occurrence of ground water from physical appearance (weak zone fracture and weathering thickness rock unit) and which geomorphologic features has relation on the occurrence of ground water.

Groundwater occurrence study involves the integrated analysis of geo-environmental variables. In this study, the existing land use pattern, slope, elevation, and hydrology datasets were used. In order to derive these datasets, Landsat satellite image of the year 2001 and 2014, Google map, DEM data, rain fall data, Topo sheets and the master plan of east wollega zone were used. The slope and elevation of the area has been generated from this DEM after being extracted using Arc-GIS 10.2 spatial analytical tools has also been used to generate hydrological networks from the DEM.

III. RESULT AND DISCUSSION

Ground water occurrence with respect to Geologic structure

The study area is highly affected by different geologic structures that control the occurrence and flow direction of ground water. The fault plane and weak zone water percolate into the ground and recharge the groundwater through the discharge zone. The study area is affected by invisible fault especially around hanger, the weak zone having tributary flow and densely populated aligned vegetation are suitable for the occurrence and flow of ground water.

The relationship between the occurrence of ground water and fracture traces for aquifers, particularly in lineaments underlain by zone of localized weathering, increased permeability and porosity. The fracture morphology can be important factor of fracture porosity and permeability which is the morphology of fracture planes. This morphology consists of three basic types of natural fracture plane morphology as follows in the study area.

- Open fracture
- Mineral filling fractures
- Deformed fracture

Fracture within volcanic rock of the study area facilitates the amount of recharge. It can store and transmit water and also it determines that ground water flows from recharge to discharge area, both surface and subsurface fractures at a location can be characterized by open and closed fracture. Open fracture can be simple apertures or permeable zones, some of which contain open cavities. Closed fractures may consist of simple fractures with hairline apertures or wider apertures sealed by secondary mineralization. Joint has an effect on the occurrence of ground water. The columnar joint of the study area has a column space, in each layered of basalt and weathered at the top which is suitable for ground water infiltration.

Ground water occurrence with respect to Geomorphology and land forms

The geomorphologic feature such as drainage pattern and topography of the study area highly affects the occurrence and flow direction of ground water. The drainage pattern of the study area has a massive compacted basalt and vesicular basalt which is dendritic are associated with uniform lithology, horizontal or very gently dipping strata and low relief, it is suitable for accumulation and transmit ion of water. Both the nature of precipitation and permeability will influence the intensity of surface run off.

Topography also affects the occurrence and flow direction of surface and sub surface water during rain fall periods, the water percolate and flow from the highland to lowland area. Topography, basin shape, structures and tectonics of the area have significant effect in dictating ground water flows and recharge condition and during rainy seasons, the water table are at shallow depth on the low land and at great depth on the high land, because the flowed water from the high land accumulates on the low land and the ground water reservoir become full, but less reservoir on the high land topography. The land forms have a great role on the ground water occurrence and flow direction. The land forms of Eastern wollega are almost dome shape and flat land. So water recharges at dome shaped and discharges at flat land.

The most common features governing the ground water flow and storage in volcanic rocks and structures of the study area are the following:

- **Vertical permeability**; Formed due to primary and secondary fractures that percolate and transmit water vertically.
- **Horizontal permeability**; Due to horizons containing openings due to the lava flow and gas expansion during solidification.

All fracture and porous volcanic rock do not always give for ground water circulation on the following regard;

- Type of frequency and distribution of fracture.
- Degrees of the fracture inter connected pore space.
- Constituents of soil cover.

At the depth, volcanic rock may have low permeability due to the pressure exerted on over lying units and also due to their compaction. The thickness of weathered part of structures also essential for water percolation and storage. That is at the top of joints having ~3m weathered thickness is suitable for ground water occurrence by storing and transmitting into the ground. The indicator of ground water around the study areas are; climatic condition, vegetation type, soil coverage, topography and geologic structure.

The ground water around the eastern wollega is not largely occurring at a great depth. Because the area get a maximum amount of rain fall per a year and its climate condition is almost wet (not dry). The densely vegetated plant the ground water occurs at shallow depth near to the surface; due to this the leaves of vegetation of the study area can not shrink and always not come to dry.

Soil type and rock structure also another indicator of ground water occurrence. The soil type of the study area has a moisture content, which is used for cultivation and crop production. Fractured basalt and columnar basalt also has a great effect on the occurrence of ground water. Fracture is used for storage and transition of ground water. Mostly the ground water potential site for the future development is found at the low land area.
Generally the ground water potential of Eastern wollega area is very high because it has high topography recharging area and low topography discharging area.

Digital Elevation and Surface Analysis

Shuttle Radar Topographic Mission (SRTM) elevation data is used for the present study to get surface data. Resolution of this data is 90m. This elevation data is analyzed in Remote Sensing and GIS software i.e. Arc-GIS 10.2 Software to get Digital Elevation Model (DEM), Slope and Aspect of the area. In the DEM, the highest elevation is 3207m and the lowest elevation is 771m (Figure - 4). However, the maximum area is covered by low elevation , which indicate the maximum possibility of the ground water. In the Slope study, the maximum slope is 56 degree (Figure - 5). Maximum portion of the study area is covered by gentle and level slope (0 to 10 degree). So, that, it is a very good topography having low land low elevation with gentle slope. This type of surface condition indicates that the water stay maximum time over the land for percolation. Aspect describes the direction of the slope. Low land low elevation terrain faces northeast, southeast, south, southwest and west (Figure - 6).

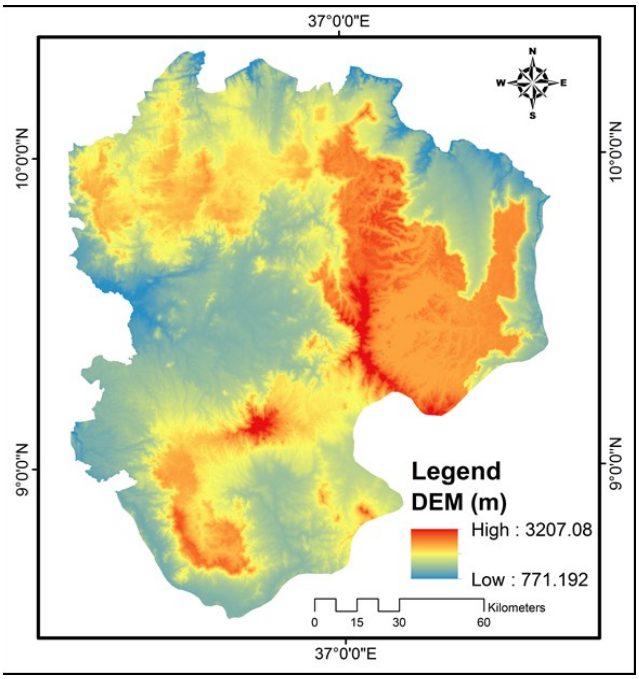

Figure - 4 : Digital Elevation Model of the study area

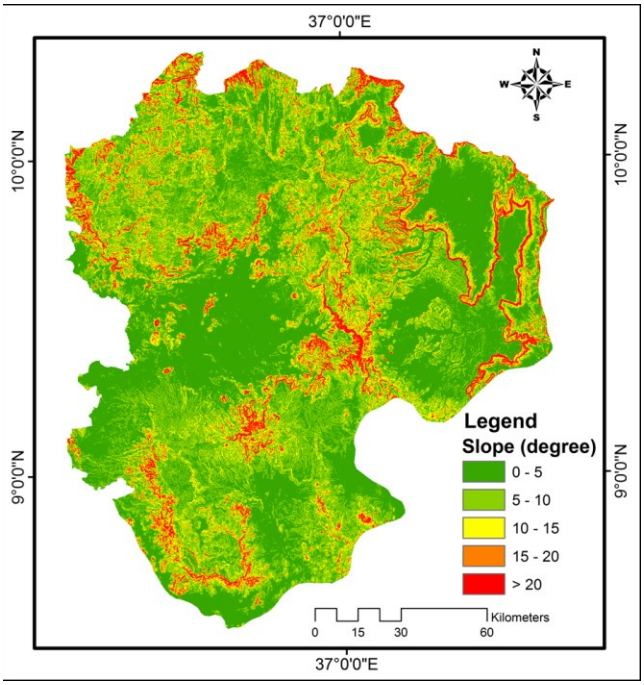

Figure - 5 Slope of the study area

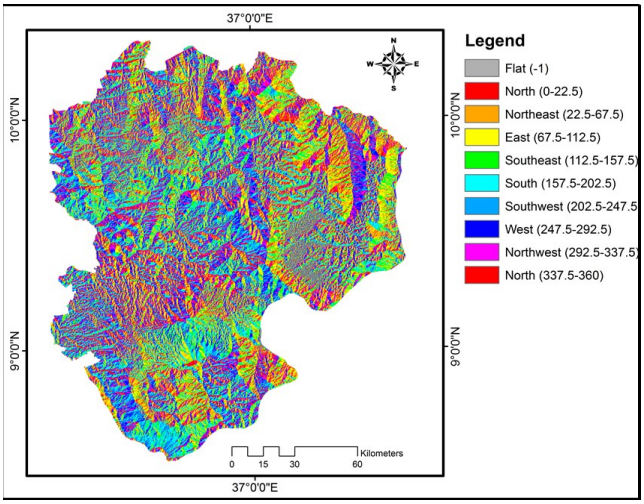

Figure - 6 Aspect of the study area

IV. CONCLUSSION AND RECOMMENDATION

Conclusion

- The occurrence of ground water is highly related with the presence or absence of geologic structure and geomorphologic land forms. These two factors are related to each other to determine ground water occurrence of the study area which has extended structures such as lineaments, tectonic structures like; faults, joint and fracture.
- Fracture basalt is very common for recharging and discharging while massive basalt neither transmits nor holding the ground water. Land forms like drainage, vegetation and soil type and climate condition also affect the occurrence and flow direction of ground water. The flow direction of ground water is from high land to low land.
- Drainage of the study area has V- shape tributaries called dendrite pattern and is mostly associated with the area of uniform litho logy. Generally, geological structures and geomorphology of the area has a great effect on the occurrence of ground water and also on its flow direction.
- Physical and morphological parameters as slope, elevation, soil, land use, and available sub surface water were derived and evaluated.
- The result obtained reveals that most of the study area were suitable to occurrence subsurface water during dry and raining seasons.
- The study also realizes that the application of GIS and remote sensing technology for appropriate and sustainable exploitation of natural resources, such like subsurface water with pot ability is planning and decision making.

Recommendation

- Depending on the geologic structures and geomorphology of the area the occurrence of ground water is better if the following given below are recommended.
- The geologic structure and geomorphology would study deeply.
- Ground water is studied by sub surface exploration method such as drilling
- The unobservable (invisible) geologic structures are studied by geophysical method. For example faults at hangar of 09 Keble of eastern wollega zone are invisible to the surface. So geophysical instruments should be needed.
- The government and related body should work on the occurrence of ground water based on the geologic structure and geomorphologic features to solve the problem of the scarcity of water for the peoples of Eastern wollega.

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