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Evaluation of ground water and land resources in relation to landforms in Alwar District (Rajasthan): A remote sensing based approach

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Abstract

Landform and topography of a place determines the recharge and transmission of ground water of a region. In order to evaluate the ground water resources, the ground water potential for the study area was computed from DEM derived parameters like drainage density, slope, parent material, accumulation parameters viz. Compound Topographic Index (CTI), flow accumulation without divergence and geomorphology (landforms). The land potential map i.e. combined soil and water potential map was generated and the potential under the various landforms has been investigated. The point data on depth to ground water has been spatially interpolated and compared vis a vis ground water potential map of the area generated from the morphometric terrain parameters. Validation of the DEM based ground water potential map with the interpolated ground recharge map shows high R^2 of 0.92. Also comparison was done considering the fractional area of a ground water depth corresponding to a ground water potential under a particular landform class. 95% of the high recharge zones correspond to the transitional landform classes viz. valley bottom and pits category of plains. Alluvial plain and colluvial plain though had high water reserve in the past are presently being depleted at a faster rate. The Poor potential areas occur in parts hilly landforms and occur rarely in plain or transitional landforms (< 5% area). Thus the transitional landforms prove to be the thrust areas where with proper management practices, the land can be brought under cultivation and has scope for cultivation with minimal management options.

Keywords: Drainage Density, Ground Water Resources, Ground Water Potential

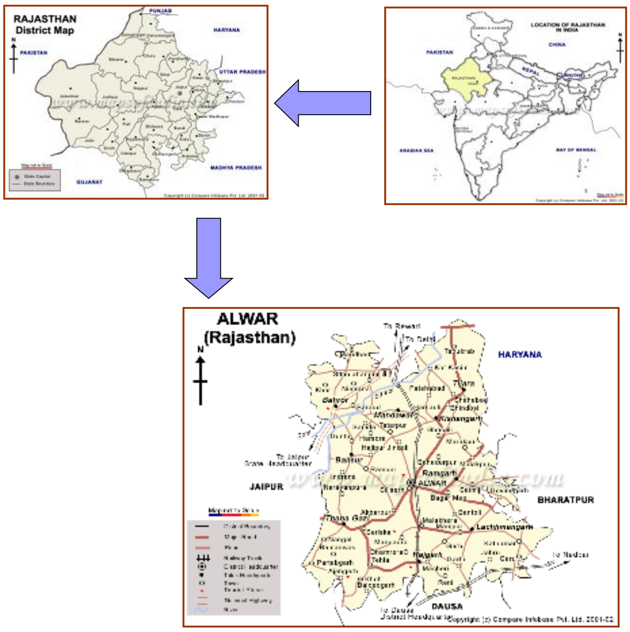
1. Introduction

Land and climatic variability has profound effects on the performance of management systems in improvements of productivity and use of natural resources. In semi-arid environments, much land use depends on water harvesting from the upper members of soil catena to support crops on the lower members. The entire process of water movement depends largely on the elevation of the area (derived terrain parameters), which goes into the process of characterizing the landforms [1]. The relationship for hydrogeomorphology, soil and groundwater prospects is established by Krishna *et al.* [2] for ecological-economic zoning in Andhra Pradesh. They reported that ground water occurence is influenced by the climate, physiography, drainage and geology of the area. They deduced the ground water potential zones after integration of hydrogeomorphological and lineament maps. The delta, transitional and flood plain are reported to have very good ground water potential followed by pediplains and Bajada and Pediments. The hills and inselbergs have no prospects of ground water. Singh *et al.* [3] reported that inspite of the stupendous efforts made to develop India's water resources; optimum benefit could not be attained. The depth to ground water in the delta was reported to be mostly shallow, of moderate depth in the transitional plains and along filled valley. Webb *et al.* [4] reported well-drained soils occur on steep sunny slopes, imperfectly drained soils occur as a transition between the above two soils. Poorly drained soils occur as a narrow fringe on plain landforms/footslopes/ valley bottom around the bog where water tables are high. Landform analysis and ground water potential in the Bist Doab area, Punjab, India was carried out by Chopra *et al.* [5]. Ferdowsian *et al.* [6] reported that the ground water level reduction under Lucerne depend on the landform and ground water flow systems. Gould *et al.* [7] studied the simulation of regional ground water flow in bedrock, southwestern New York. Specific terrain attributes associated with presumed hydric soils include concave slopes of low gradient located < 1 to 2 m above the lowest elevation of the local topographic depression. We also encountered a comparable situation in our study region. The mathematical morphometry based approach which characterizes the landforms increases the understanding of the location of the ground water potential zones as well [8]. The study area had good potential of ground water two decades earlier. Due to introduction of wheat in *Rabi* (winter) season there has been need for irrigation which has led to depletion in ground water level in recent past. But still the area is less modified as compared to others hence selected. The present paper deals with the study of intricate relationship of the terrain parameters which determine the landform of a place after sequentially giving weights to the terrain parameters and in turn influence the ground water prospect of a region [1,9]. The landform derived ground water potential and the ground recharge map from interpolated point data has been compared to validate the profoundness of the first method.

Study Area

The study area comprises of Alwar district of Rajasthan as seen in Fig. 1. Physiographically, western Rajasthan is covered with sand dunes while the eastern, southern and southeastern parts are rocky and hilly with very few alluvial plains. Surface water sources are meager and the entire state has always been principally dependent on groundwater for its water needs. It comes under Agro-Ecological Region 4 and Eco-Sub region N8D2 (Dry Semi Arid). Northern Plain (and Central Highlands) including Aravallis, hot semi-arid ecoregion (N8D2). North Punjab Plain, Ganga - Yamuna Doab and Rajasthan Upland, hot semi-arid with deep loamy alluvium-derived soils (occasional saline and sodic phases), medium Available Water Capacity and LGP (length of growing period) 90-120 days (N8Dd3) [10]. The latitudinal extent is from 27° to 28° N and longitudinal extent is from 76° E to 77° E. The soils of the area are broadly of coarse texture and the prevalent soil order is Inceptisol. The natural vegetation comprises of scrubs in the elevated part and semi arid vegetation in plains. The predominant crops are wheat and mustard in *Rabi* (winter) season and bajra in kharif (rainy) season. Wheat requires more water (300 - 400 mm) as compared to mustard. It is located in the undulating terrain of aravalli landscape where a variety of landforms can be found within a small stretch of land of around 120 km.

Figure 1. Study area



Geohydrology of Rajasthan

Rajasthan lies over some of the oldest rock formations in India. The State has a heterogeneous assemblage of geological formations ranging from the oldest Archean to recent alluvium and blown sand [11-13]. All of the lithological units have some groundwater potential; however, the water potential of these formations depends on their hydrogeological characteristics and structural control. The groundwater potential areas in Rajasthan are not widespread and homogenous, but found as isolated basins with unique hydrological parameters. Also, the quality of the groundwater depends entirely on the site-specific physical properties of the formation, the extent and nature of weathering, and other specifics. There is considerable knowledge of the regional geological formations and mega-structures, and of the extent of weathering. However, the information generated is inadequate to correlate with the groundwater potential of any specific area.

Geomorphological Characteristics

According to Singh *et al.* [14], the geomorphological characteristics of Rajasthan can be broadly divided into four major geomorphic regions. These are, from west to east, (1) the Rajasthan desert, (2) the Aravalli Mountains, (3) the east Rajasthan plains, and (4) the southeastern plateau.

Hydrogeological Conditions

Hydrogeological characteristics of the various lithological formations, such as depth of groundwater, yield, and etc., are of vital importance in studying the groundwater potential in any area. The State Ground Water Department (SGWD), in 1977/78, identified 28 types of aquifer and grouped them into 13 hydro-geological zones. Subsequently, better data and information on hydrological properties of various aquifers and their extent were generated and these groups were reclassified [15]. Based on detailed information of these 13 aquifer types, the SGWD divided the State into seven provenances, each with similar groundwater characteristics, including water quality. These provenances are: hard crystalline rock consolidated sedimentary rock, semi-consolidated cavernous rock, semi-consolidated sedimentary rock, basaltic, unconsolidated to poorly consolidated sedimentary rock and alluvial.

The above mentioned area has been selected for study firstly, as there is appreciable variation in the altitude (187-717 m) and therefore, wide ranges of landform features are expected. Secondly, most of the landforms management practices are natural except for irrigation. No major soil conservation strategies have been implemented and the relationship of soil and landform features with the agricultural productivity will be, as they existed in the natural ecosystem. In other parts, such an undulating topography is managed for soil conservation, which modifies the whole set up of soil formation and agricultural productivity. Thus this area provides a natural environment for studying landforms in relation to water resources.

2. Materials and Methods

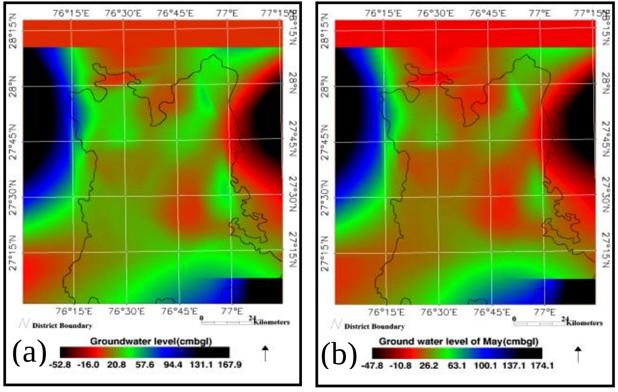
2.1. Datasets

Shuttle Radar Topography Mission (SRTM) DEM (3 arc seconds/ 90 m) data freely available was downloaded for the study. Survey of India Topographical maps - 1 : 50,000 and 1 : 250,000 (54 A and 53 D in parts) has also been used for the study. Data processing package ENVI 4.2 and ILWIS Academic 3.0 have been used for data analysis during the study. The DEM was used for calculating the terrain parameters viz. slope gradient (SLOPE), aspect (ASPECT) profile curvature (PROFC), Plan curvature (PLANC), shaded relief, compound Topographic Index (CTI), Stream Power Index (SPI), Shape complexity Index (SCI), Flow Accumulation without flow divergence, Solar radiation, LS - Factor, Catchment area were calculated from the DEM, which implements the Zevenbergen and Thorne [16] formulas. The five terrain parameters, namely elevation (0 order differential), slope, aspect (1st order differential), profile convexity, plan convexity (2nd order differential) and other related parameters like mean curvature and shape complexity index was extracted. The hydrological parameters like Compound Topographic Index (CTI) and Stream Power Index (SPI) were calculated using the inputs from the DEM [1,9]. Various morphometric parameters were derived from the DEM, given sequential and suitable weights to generate the landforms and these were evaluated to generate ground water potential independently. Ground water data in form of well logs has been used in the study to compare with the DEM derived ground water potential map. The data was obtained from Ground Water Board, Jaipur. The ground water board data for 5 years from 1997 to 2002 was received for 31 well logs stations in the Alwar District, Rajasthan. Ancillary information on the crops of the study area was also collected during the ground truth.

2.2. Evaluation of Ground Water Resources

For the ground water recharge and potential study, the data of May (Pre monsoon) and August (Post monsoon) was analyzed (Fig. 2). The later season data of November and January were not used; as they will be have the effect of subsequent depletion due to extraction mainly for irrigation purposes for growing *Rabi* crops. Ground water fluctuation was studied by considering the recharge from May to August to see the effect of monsoonal recharge. The annual normal rainfall of the area is approximately 69.5 cm (Watershed Atlas of India, 1998). The Ground water well log data in units of mbgl (Meter Below Ground Level) was available. To enhance the visibility of the fluctuation the units were converted to cmbgl (cm).

Figure 2. Ground water level in the study area (cmbgl) (a) May (b) August



Then, the point data was rasterized and spatial map of Ground water Depth and Ground water fluctuation was generated. For assessing the Ground Water Potential, a methodology has been developed by giving suitable weights to the parameters viz. landform type (hydrogeomorhology), drainage density, parent material, Compound Topographic Index or wetness index (CTI), Rho 8_Catchment which is a measure of flow accumulation without divergence which affect the ground water resource potential in order to quantify the recharge [1,9]. CTI describes the accumulation process and has been found to be indicative of the position of a particular landform in the terrain. It is also termed as wetness index and quantifies the accumulation process, which occurs as a result of deposition of sediments along with water from the elevated areas to the lower parts. Flow accumulation without divergence (Rho_8 catchment) has been computed and it shows the regions associated with higher flow accumulation. These locations adds to recharge of ground water and are observed to occur under areas of high ground water potential in the plain categories (alluvial plain, colluvial zone, and pits) and the transitional categories specially the valley bottom areas and some parts of footslopes. A sample of weights given is described in Table 1 and subsequently derived a map of low to high potential zones. Hadithi *et al*. [18] followed a methodology in this line but we have used additional parameters as mentioned above.

The parameters, which favor the ground water recharge viz. less slope of the land, geomorphology in terms of landform (plain or transitional type), Compound Topography Index (high value), Flow without divergence (high value), drainage density (low value), and parent material (alluvial and colluvial type) were given high positive values and the unfavorable parameters low positive values.

Table 1. Hydrogeomorphology and their corresponding weights

Landform type (weights)	Compound Topographic Index (CTI) (weights)	Flow accumulation without divergence (Rho_8 catchment) (weights)
Alluvial, colluvial or pit (5)	> 12 (2)	200 – 255 (2)
Valley bottom or footslope (4)	8 – 12 (2)	150 – 200 (2)
Pediment or bahada (3)	4 – 8 (1)	100 – 150 (1)
Ridge or backslope (2)	< 4 (0)	< 100 (0)
Illuminated peak (1)	< 4 (0)	< 100 (0)

Finally, the ground water potential map was obtained and was categorized as the sum of weights given to all these parameters. The higher the summed weight indicated higher positive recharge and may be zoned as water extractable land (Table 2). Subsequently the land capability classes as discussed hereunder were given weights based on soil properties as shown in Fig. 5.

Table 2. Ground water potential based on their summed corresponding weights

GW Potential (summed wts)	Class
< 12	Poor
13 – 15	Moderate
16 – 18	Moderate to good
> 19	Good to very good

2.3. Soil Resource Evaluation and Land Capability Classification

The needed soil parameters were extracted from the NBSS & LUP soil map. Various thematic maps of the different soil properties were prepared in ARC-VIEW GIS. The soil map of NBSS & LUP [19] and Rajasthan soils in 1 : 1,000,000 and 1 : 250,000 scales were used. The analysis of the dominant soil properties in a particular landform class is studied. The soil properties analyzed in this manner are soil depth, soil drainage, sodicity, erosion, calcareousness, flooding, particle size, pH, parent material, salinity, texture, stoniness, and Taxonomy. The percentage area of a particular landform, which falls in a soil parameters class, was computed using the corresponding landform mask. The percentage area under a particular landform accountable by various taxonomic classes has also been computed. Finally the land capability classification of the study area is carried out.

For carrying out the land capability classification, the deciding soil parameters as per the standard methodology by Sehgal [20] has been used and based on the potentialities and limitations. The limiting parameter was used to decide the land capability class. The methodology followed is described as follows was implemented in ARC - VIEW GIS.

a. Depth id > 5 and Drainage id = 5 or Drainage id = 6 and slope id ≥ 2, and slope id ≤ 3 and erosion id ≤ 2 then the land is classified under Land capability class II.
b. Depth id ≥ 3 and Erosion id ≤ 3 and slope ≤ 3 and drainage = 8, then the land is classified under land capability class III.
c. Depth id ≤ 5 and Erosion ≤ 3 and slope ≤ 3 and Drainage ≥ 6, then class III is the Land capability class.
d. Depth id = 3 and Erosion id ≥ 2, and slope id = 3 then the land capability class is IV.
e. Depth id = 0, and drainage id = 0 and Erosion id ≥ 4 and slope id > 4 then the land capability is class VII.

The percentage area of a land capability class under a particular landform is studied. The id values for various soil parameters as given in the NBSS & LUP soil map have been used. NBSS & LUP publ. 51 [19].

Finally from the soil (Land capability weight image) and ground water potential image, the combined map is generated again from two single images to quantify the resource potential in terms of both soil and water potential. The ratings given to the combined soil and water potential image is shown in Table 3. A class wise comparison was made for the water potential map (derived from DEM based parameters) and the water recharge map from the ground water depth data. The point data on depth to ground water has been spatially interpolated and compared vis a vis ground water potential map of the area. This comparison was done considering the fractional area of a ground water depth falling under a particular ground water potential class. Also at least 5 random samples were taken from each dominant landform categories in the ground water potential map and the value of May to August recharge for these corresponding points were noted down. Under a particular landform category the potential class that shows predominance was examined and the studied as discussed below.

Table 3. Weight range of the final image denoting land potential map

Weight range of the combined image	Weight assigned finally	Remarks
2 & 3	1	Poor
4 & 5	2	Moderate
6 & 7	3	Good
8 & 9	4	Very good

3. Results

3.1. Ground Water Resources in Relation to Landforms

Ground Water Recharge

The ground water data for the study area was processed as described in the previous chapter. Figs. 2 (a) & (b) shows the ground water level in the study area. The image in the left shows the ground water level in the month of May (Pre Monsoon) and the image in the right shows the ground water level of August (Post Monsoon). Northern and north eastern part in the May image is converting to greenish part in the August due to recharge (i.e. ground water depth is decreasing). In the central right part, both the images show dark red part due to more water extraction than recharge specially for irrigating the *Rabi* (winter) crops. The dark blue and red (high negative) outside the district boundary is due to the extrapolation error of the well log data (31 well log data points are available for the district). In the right corner (North - East part of the District Boundary) high recharge is found due to presence of high recharge zones in this area (pits category of landform). The ground water fluctuation from May to August due to recharge in most parts of the study area is shown in Fig. 3. The North - Eastern sector and Western sector show high recharge zone in the study area after the monsoon.

Figure 3. Ground water fluctuation map of May and August

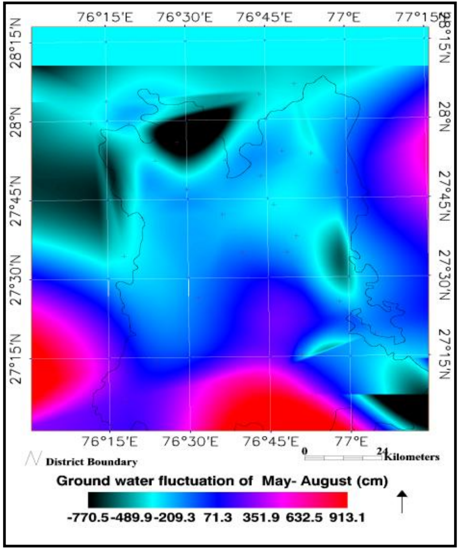


Figure 4. Ground water potential map

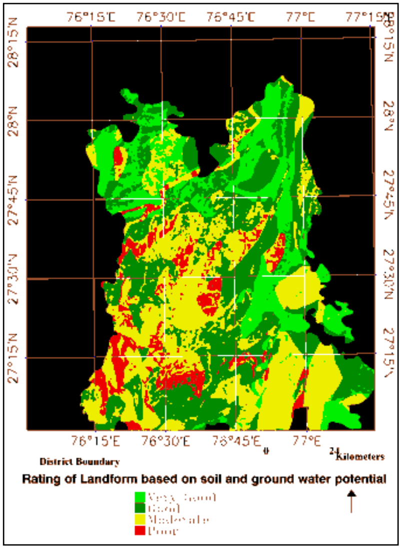
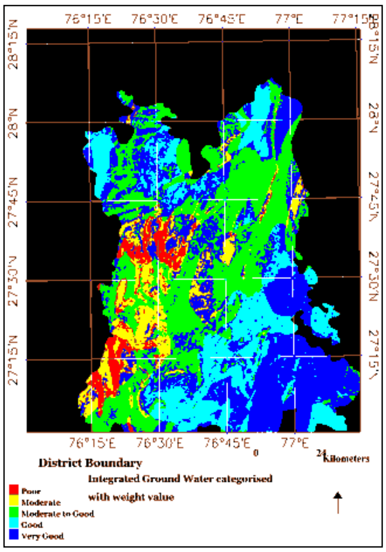


Figure 5. Land potential map



Drainage Density

The drainage density of the study area has been computed basin wise. The Drainage Density < 0.149 is given weight of 5 and > 0.3 given weight of 1 with intermediate values given intermediate weight. The polygons with high drainage density are subjected to less recharge due to diversion of the water from the recharge cells/sites. The Ground water potential (integrated ground water categorized with weight value) considers one parameter as the drainage density as it has direct impact on recharge volume.

Ground Water Potential Zoning

The morphometric parameters derived from DEM have been used for generating the GW potential map as described in the previous section. The parameters, which favor the ground water recharge viz. less sloppy land, landform (plain or transitional type), Compound Topography Index (high value), Flow without divergence (high value), drainage density (low value), and parent material (alluvial and colluvial type) were given high positive values and the unfavorable parameters low positive values.

The ground water potential map of the study area is shown in Fig. 4. The valley bottom and foot slope areas show moderate to good (Green) and good (Cyan) areas due to prevalent recharge zones in this area. 95% area of the high recharge zones correspond to the transitional landform classes viz. valley bottom and pits (plain landform) which acts as basin to confine the ground water.

4. Discussion

The water level in northern and eastern part in the August image is increasing due to recharge and subsequently decreases during November due to extraction by *Rabi* crops. The central part indicates the less recharge zones as in evident due to high water extraction in this zone due to more of cropped area in *Rabi* season.

The higher well yield for wells located in valley bottoms and flat lands may be explained by a greater infiltration of surface water because of the generally thicker superficial cover and additional recharge from surface water bodies in these hydrogeologic settings. The valley bottoms are also discharge areas for ground water flowing from higher elevation catchments. Henriksen *et al.* [21] reported similar observations when they studied relation between Topography and well Yield in Boreholes in Crystalline Rocks Sogn og Fjordane, Norway. The relationship between topographic site and well performance, seemingly independent of lithology, indicates that the lithologic factor may be subordinate to factors related to topography and hydrology of the catchments area.

Figure 6. GW potential versus GW fluctuation (negative values indicate higher recharge)

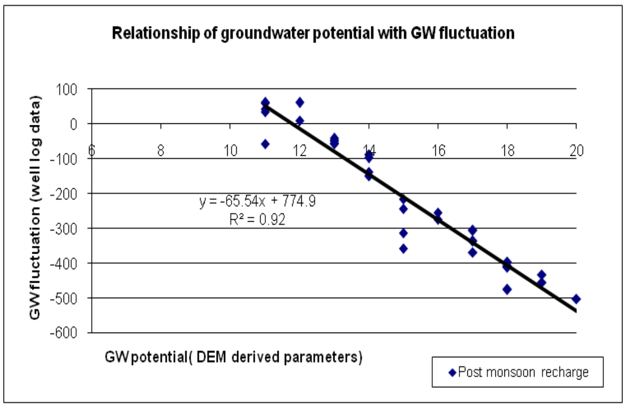
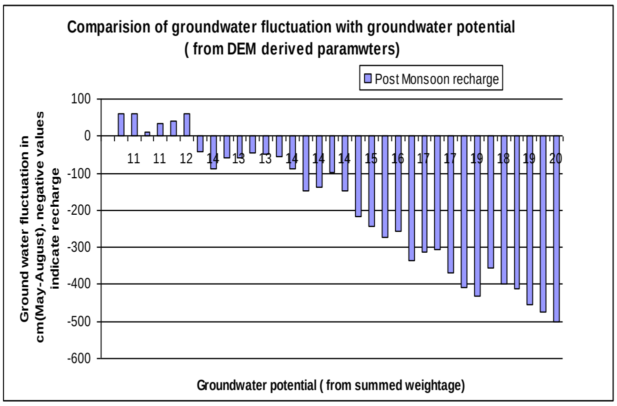


Figure 7. High correlation between GW potential and GW fluctuation, higher recharge (negative values)



Alluvial plain and colluvial plain though had high water reserve in the past are presently being depleted at a faster rate due to extraction for irrigation. The poor potential areas occur in parts hilly landforms and occur rarely in plain or transitional landforms (< 5% area). The hilly landform area dominated by peak, illuminated peak, back slopes and ridges show predominance of poor (red) and moderate (yellow) ground water potential. Much of the very good land (blue) is converting to good (cyan) and moderate potential (green) areas. Poorer categories in the alluvial landforms occur due to injudicious exploitation mainly in these areas during *Rabi* season. The first accumulation mechanisms reflect surface flow conveyance. For one part of the surface flow lines can converge (plain and transitional), for others diverge (hilly landforms).

4.1. Land Potential Evaluation

The land potential map generated by combining the land capability classification and the ground water potential map is shown in Fig. 5. The poor land potential region occurs in parts of hilly landforms and very little in plain. Moderate soil and water potential occur mainly in hilly and major share of the plain. The transitional landform and some parts of plain have area under very good (bright green) and Good (dark green) Land. Thus the transitional landforms prove to be the thrust areas where with proper management practices, the land can be brought under cultivation.

4.2. Ground Water Potential Comparison with Ground Water Recharge

A comparison of the ground water potential based on the above methodology based on various parameters including landform (which is a dominant parameter) and the ground water depth map (generated from point data) was carried out. Fig. 6 shows the plot of some randomly selected ground water recharge points over the study area and the corresponding ground water potential derived from DEM based parameter. The negative value (lower depth to Ground water) indicates favorable recharge. Moderate and good potential zones with summed weights > 15 correspond to recharge of minimum 150 - 200 cm. Fig. 7 shows a validation plot with high correlation of recharge and ground water potential with R^2 of 0.92. The shallower depth corresponds to the plain and transitional landforms indicating a good potential zone (Table 4) whereas deep ground water occurs in transitional to hilly land. This forms a validation of the parameter based assessment and the actual GWD based potential. Area based Ground water potential comparison based on the ground water depth data versus the landform map generated from DEM are presented in Table 4. Around 70% of the area of plain and transitional landform is under high recharge zone (good to very good category).

About 70 cm or more recharge is observed in the plain and transitional landforms. This comparison was done considering the fractional area of a ground water depth falling under a particular ground water potential class. Good to very good indicates water is at shallow depth.

Table 4. Area of the landform under classes of ground water potential

GW potential/Landform	Poor (deep)	Moderate (mod deep)	Moderate to good (slight deep)	Good to very good (shallow)
Valley bottom	0	3	23	74
Backslope	95	5	0	0
Colluvial zone	0	2	26	72
Pit	0	1	24	75
Alluvial plain	0	5	25	70
Illuminated peak	100	0	0	0
Peak	100	0	0	0
Footslopes	25	12	60	3
Ridge	41	25	28	5
Pediment	42	27	30	1
Bahada	41	26	31	2

5. Conclusions

Ground water recharge zones was found to be mostly confined to the pits region in the plain landform and valley bottom region in the transitional landform as because ground water recharge occurs in the zones where standing water remains for sufficient long period of time and has favorable condition for recharge. High soil and water potential are mostly confined to the plain land (parts of alluvial and pits) and in transitional landforms (plain). 95% area of the high recharge zones correspond to the transitional landform classes viz. valley bottom and plains (pits) which acts as basin to confine the ground water. Alluvial plain and colluvial plain though had high water reserve in the past are presently being depleted at a faster rate due to extraction for irrigating *Rabi* crops. The Poor potential areas occur in parts hilly landforms and occur rarely in plain or transitional landforms (< 5% area). The soil (estimated by soil properties) and water potential (estimated by several weighted parameters) have a close correlation with each other as presented in land potential map. This can be used for optimized use of resources based on the water potential of an area. The transitional landforms prove to be the thrust areas where with proper management practices, the land can be brought under cultivation. Area based Ground water potential comparison based on the ground water depth data versus the landform map generated from DEM was carried out. Moderate and good potential zones with summed weights > 15 correspond to recharge of minimum 150 - 200 cm. The validation plot shows high correlation of recharge and ground water potential with R^2 of 0.98. The landforms were rated on the basis of their potentials and limitations in terms of the choice of the crops and cultivation practices.

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