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Spatial Distribution of Groundwater Level over Lowlands of Morang District of Eastern-Nepal

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ABSTRACT

A better understanding of spatial distribution of groundwater level is necessary for the development of groundwater development strategies and sustainable use of available resources. The present study evaluates the spatial distribution of groundwater level over the Morang Administrative District of Eastern Nepal and the groundwater accessibility over the area. The study was realized by performing an extensive field survey of groundwater level during the post-monsoon season over 126 sites. The study area of 1224.80 km^2 was gridded at 3 km x 3 km horizontal grid resolution and at least one survey was ensured for each grid point. Downscaled spatial distribution of groundwater level was achieved by interpolating the observed data using the Inverse Distance Weighting (IDW) with different weighting parameters available with the geostatistical module of ArcGIS. The performances of the interpolation methods were evaluated based on the cross-validation of results characterized by the statistical parameters RMSE, R^2 and MAE and optimal power (α) for weighting function. The IDW (with α=4) appears to perform well for the study area with Coefficient of Determination (R^2) and Root Mean Square Error (RMSE) and Mean Absolute Error (MAE) values of 0.336, 4.750 and 2.967, respectively. The spatial distribution of groundwater level over the low-lands of Morang District mapped with the IDW interpolation method, revealed that the ground water level is maximum in south-western part of the district. The depth to groundwater lies between the ranges of 4.5 to 10 meters covering almost 67.47% of the total study area.

Keywords: Groundwater, IDW, Spatial Interpolation, Morang, Nepal.

1. INTRODUCTION

Groundwater (GW) is the water that accumulates underground which is major source of fresh water. The depth and the amount of GW vary by place and influenced by geology, geomorphology, physiography, of that place. Rainfall and subsurface water are the major source of GW recharge [1]. The unique physiography of Nepal is divided into several refined regions with high Himalayas (including Mount Everest, 8848 m) in the northern part followed by Central Hills to lower lying Siwalik (including Chure hills) and the “terai’ or flat river plains at the southern region [2]. The higher Himalayas on the northern part characterized by crystalline rocks, from poor aquifers compared to molasses sediments of Siwaliks, and non-karstic but fractured carbonate rocks in the Central hills and Tethys group. On the other hand, Terai and inner Terai, the southern Terai region adds up to multiple layers of interconnected and non-connected good aquifer at different depth [1, 3]. The country’s utmost dependence on GW is over-exploiting the unconfined, quaternary aquifer of Terai region. Almost a million and more tube-wells are installed in Terai alone to meet the daily domestic water requirement. 90% of the total residents depend on these tube-wells extracting 462 million cubic meters of GW annually for domestic purposes [1]. GW sources are continuously recharged but over exploitation of GW for various purposes like irrigation and domestic uses causes decline in water level [4], therefore the regional GW assessment is immediate. Figure 1 depicts the dependence of local people on groundwater in low-lands of Morang District of Eastern Nepal.

Fig. 1: Snapshot picture of tube-well drilling by local drillers in different places of study area during the field survey. *(Picture: Ashish Bhattarai)*

Geo-scientists rely on the available depth to GW level data which can be interpolated using different spatial interpolation methods to understand the spatial and temporal variation of GW [5]. The data obtained from the sampled locations are used to predict values at un-sampled points by various interpolation methods. The approach to interpolation technique may be Stochastic namely, Ordinary Kriging (OK), Universal Kriging (UK), Simple kriging (SK) and so on or Deterministic namely, Inverse Distance Weighting (IDW), Radial Basis Function (RBF), Natural-neighbor etc. [6]. This paper presents a spatial map of GW level of the study, are based on IDW method.

Among numerous deterministic approaches, IDW is popular and still relevant as it is free from tedious computational algorithms. In fact, it is concise, easy to understand and available in many GIS packages. The IDW assumes that each input point has greater influence on nearby cells that gradually decay with distance [7]. The prediction accuracy of the IDW interpolator over other interpolation techniques have been presented in many studies. Recently, a study [8] has interpolated the water level measurement from borehole piezometer in Singapore using geo-statistical analysis available in ArcGIS for both wet and dry seasons. The performance of the IDW and OK shows almost similar result with $r^2 > 0.81$, illustrating the fact that the IDW can be used as an interpolator for GW mapping in different parts of the world. The water level measurements from 206 wells in Baghdad Governate are interpolated using the IDW and the kriging method, in which the predicting accuracy of IDW is reliable with fewer errors [9]. In context of Nepal, The GW table and quality map of Bhaktapur district is prepared using GIS-based IDW interpolation technique [10]. The spatial distribution of GW, reflects the present status of the GW level in the study area, is important to understand the factors leading to its over-exploitation and adopting sustainable water usage practices.

2. MATERIALS AND METHODS

2.1. Research site and data collection

The geographical location of the study area and the observation points is shown (see Figure 2) that spreads between the latitude 26°20' to 26°45' N and longitude 87°15' to 87°45' E [11]. The western part of the area is separated from Sunsari by *Budhi Khola* and Eastern part is separated from Jhapa by *Mawa Khola* and the southern part shares border with India. East-west highway eases all type of road transportation as it passes through the middle of the district [12]. The lowlands of Morang cover an area of about 1224.80 sq. km with altitude ranging from 60 m – 163 m which is favored by sub-tropical climate. The study area is characterized by a multi-layer aquifer system connected laterally where intermittent clay formations occur as lenses and layers. The GW extraction potential for the area is more than 39 million cu. $m\ hr^{-1}$ [11]. The study area is divided into the square grids of size 3 km × 3 km using ArcGIS 10.7, location and Global Positioning System (GPS) coordinates of each grid point are traced using free license software, Google Earth Pro. A field survey was conducted at 126 grid points to collect depth to GW data.

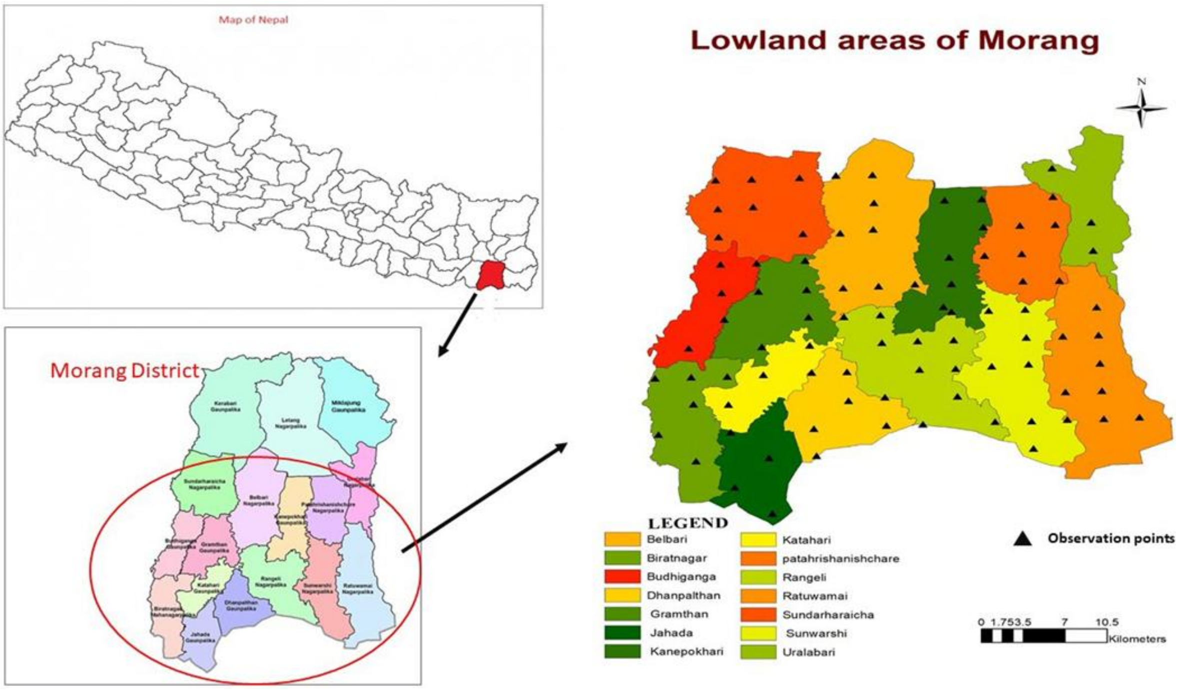

Fig. 2: The Morang district in the map of Nepal as prepared using the ArcGIS 10.7.1. The triangles in the inset (right figure) show the survey points of groundwater depths.

2.2. Inverse distance weighting

The IDW is one of the deterministic models which are exact and convex. The details of IDW are discussed elsewhere [7, 13]. This particular method, a standardized formulation available in almost all the GIS packages, is widely used by geo-scientists. It estimates the value at some un-sampled location *Z(S₀)* at a distance S_0 as a linear combination of weights λ_i and observed Z values sampled at locations S_i such that:

$$Z^*(x_0) = \sum \lambda_i Z(x_i) \quad (1)$$

With $\boldsymbol{\lambda_i}$ defined as:

$$\lambda_i = \frac{d_{0i}^{-\alpha}}{\sum_{i=1}^{n} d_{0i}^{-\alpha}} \quad (2)$$

where,

$$\sum_{i=1}^{n} \lambda_i = 1 \quad (3)$$

The numerator in equation (2) i.e., $d_{0i}^{-\alpha}$ is the weight function which depends on the distance between S_0 and S_i and varies with power 'α' and denominator is the sum of weight function. The weight λ_i depends upon the distance between S_0 and S_i smaller the distance between them larger will be the weight and vice-versa. The weighting is controlled by weighting parameter 'α' which decides how the weight drops off as the distance increases. When the value of α is unity is simply the inverse of distance; for α = 2, is the square of inverse of distance and so on. The spatial variation of GW of the lowlands of Morang is estimated adopting three different power parameters *viz*. 1, 2 & 3 resp and, their accuracy can be estimated by using cross-validation process [14, 5, 6].

In this study, the most commonly used statistical parameters *viz.* Coefficient of Determination (R^2), Root Mean Square Error (RMSE), and Mean Absolute Error (MAE)) were used to evaluate the performance of interpolation techniques. It can calculate the forecasting errors within the data set and is computed using the formulation [15]:

$$R^2 = \left(\frac{\sum Z_i Z - \frac{\sum Z_i \sum Z}{n}}{\sqrt{\left[\sum Z_i{}^2 - \frac{(\sum Z_i)^2}{n}\right]\left[\sum Z^2 - \frac{(\sum Z)^2}{n}\right]}} \right)^2 \quad (6)$$

$$RMSE = \sqrt{\frac{\sum(Z_i - Z)^2}{n}} \quad \text{..(7)}$$

$$MAE = \frac{1}{n}\sum|Z_i - Z| \quad \text{..(8)}$$

Where, is the predicted value, Z_i is the observed value, and Z is the number of observations. The weighting parameter of IDW yielding the highest R^2 and the lowest MAE, RMSE is selected as the optimal power to map GW in the study area.

2.3. Tools and Software

GIS is widely-used, highly-demanding tool to collect, analyze and visualize spatial and non-spatial data which is equally preferred in environmental and earth science research [16]. Google Earth pro is used to visualize satellite images terrain and 3D objects and also used to import and export data from GIS and vice-versa. The statistical calculations are computed and visualized using MS office packages.

3. RESULTS AND DISCUSSIONS

3.1. Statistical Analysis

The characteristics of gridded data set observed from 126 sites over the study area during post-monsoon of the year 2019 is summarized in the Table 1. The mean of data set is 8.8568, median: 7.1628 and Standard Deviation (S.D) is 5.7845. The skewness and kurtosis are found to be 2.2524 and 6.378 respectively.

Table 1: Descriptive statistics of groundwater depth dataset

Sample size, n	Minimum (m)	Maximum (m)	Mean (m)	Standard Deviation (m)	Skewness	Kurtosis
126	3.04	32.04	8.86	5.79	2.53	6.38

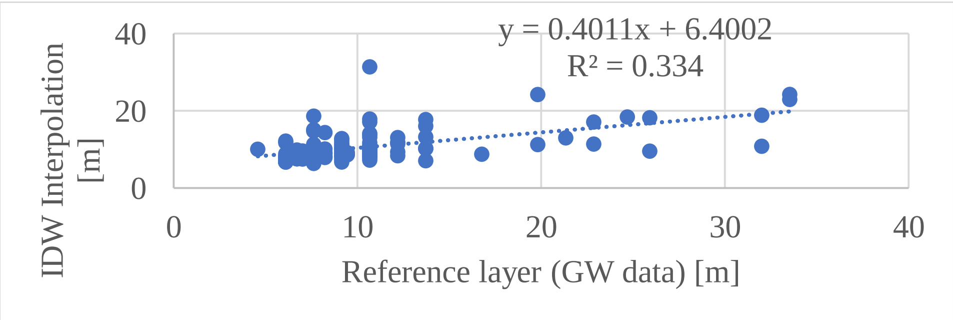

Fig. 3: Scatter plot of measured vs predicted GW table value.

3.2. Performance analysis of interpolation method

The GW table data is interpolated using IDW technique for four different values of weighting parameter 'α' i.e., 1, 2, 3 and 4 and the performance is evaluated by comparing the values of R^2, RMSE and MAE (see Table 2).

Table 2: Performance evaluation of IDW for different weighting parameters

IDW Weighting parameter (α)	R^2	RMSE	MAE
1	0.317	4.801	3.168
2	0.327	4.732	3.073
3	0.325	4.751	3.016
4	0.334	4.750	2.967

R^2 Coefficient of determination; *RMSE* root mean square error; *MAE* mean absolute error.

3.3. Spatial Distribution of Predicted GW level

The spatial distribution of GW level in lowlands of Morang District area as predicted by the IDW interpolation module is visualized in the Figure 4. It can be seen that about 67.47% of the total study area holds groundwater level in between 4.5-10 m below the ground surface whereas the study conducted nearly three decades ago had predcited GW table depth 1-5 m below the ground-level [11]. The areas of *Sundarharincha* have the shallow aquifer at the depth less than 6 m from the ground surface whereas the areas of *Biratnagar* and *Kanepokahari* have aquifer deep below the surface ranging upto 34 m.The GW of *Biratnagar* seems to be over-exploited due to greater population density and the deep GW table in *Kanepokhari* may be the consequences of over-exploitation of GW for irrigation as this area is extensively farmed.

Table 3: Predicted areas of groundwater depth distribution.

Groundwater depth (m)	Area (%)
4.5-6	0.51
6-8	40.22
8-10	26.74
10-12	15.14
12-14	6.83
14-16	1.71
16-18	1.29
18-20	1.49
20-22	1.39
22-24	1.19
24-26	1.22
26-28	0.4
28-30	0.36
30-32	0.75

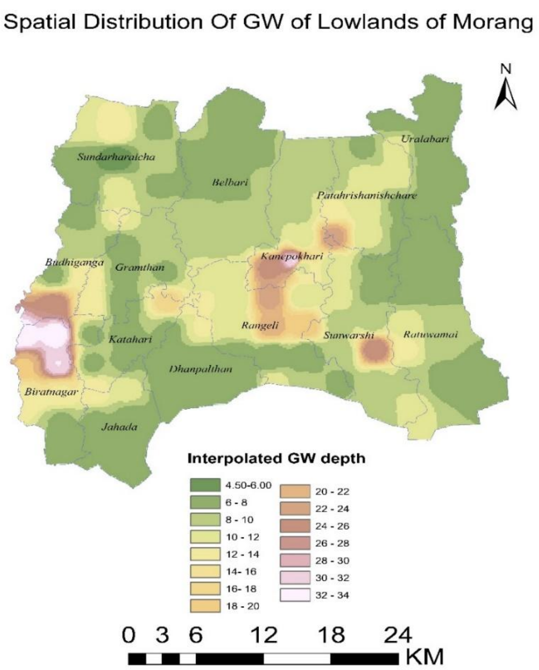

Fig. 4: Predicted GW depth using IDW interpolation

As predicted by previous study [11], Northern and mid-eastern part has deeper water table depth which is in good agreement with our findings (see Figure 4), where *Pathari, kanepokhari* and Rangeli area has water table depth below 20 m exceeding to the highest in the study area. Southern region of the study area with lower population density but higher crop fields have shallower depth to GW.

4. CONCLUSION

The spatial distribution map of GW depth of the low-lands of Morang District is obtained using IDW interpolation technique in ArcGIS. Based on the statistics, the optimal power or the value of weighting parameter for GW mapping in the study area is found to be 4 which has relatively higher prediction accuracy with less errors. The outcome of the study is the generation of spatial distribution map of GW in the study area and to understand the present status of GW in the region which will help local government to form water uses policies. The spatial dependence of GW in the low-lands of Morang is moderately associated. The areas that depend upon GW for irrigation and heavily urbanized areas have relatively deep GW depth as compared to other regions. This could have been resulted due to over-exploitation of GW to fulfil the daily need. Though, most areas have moderate GW depth, unscientific extraction and concretization may cause scarcity of GW in near future.

As compared with the earlier study GW level is found to be depleted seriously in the study area, over three-decade time frame GW is found to be depleted by almost three times which is a very serious issue. This should coerce government to preserve natural sources by regulating unscientific extraction of GW. Besides, controlling the over-extraction, there is also need to study and implement techniques to recharge GW. Rain water harvesting plants and GW recharge pits should be compulsorily constructed while constructing residential as well as business buildings. The study also realizes the extensive research and maintenance of proper database of GW table for the future use.

This study serves as a major sheet of reference to the local administrative bodies of Morang for formulating guidelines for the extraction and use of GW.

5. FUTURE PROSPECTUS

This work can be expanded to study the spatial distribution of GW throughout the nation. The assessment of temporal variation of GW can be done based on the study. Since, most of the residents of Morang use GW directly for drinking, the quality of groundwater should be properly examined.

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