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Ground Water Profile of a Small Agrarian Watershed on the Foothills of Western Ghats

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Abstract: Groundwater is the most tapped fresh water source. Timely availability is the reason for its reliability. Temporal groundwater fluctuations are quite natural aspects perhaps never be ignored hydrologically. This work demonstrates the heterogeneity in groundwater levels and predicts the levels for a small agrarian catchment for a rivulet named *Ujire Halla*. About 25 water wells, distributed well within the watershed, have been observed regularly to understand the groundwater health. So sampled 6-week data, falling in November to March, is interpolated to the extents of watershed. The spatial interpolation has been carried out using a well worse method, called Kriging. The accuracy of Kriging in every prediction is expressed by variance. The results obtained infer about the ground water fluctuations. The fluctuations are more in the northwest to the core parts of the catchment. Fluctuations are also affected by the alternate source of water supply arranged by local bodies. Further, with the availability of spaces one can practice rooftop rainwater harvesting or the runoff can be recharged to the openwells to level the fluctuations. The region wise stress on groundwater can be managed by adopting some land management practices as well.

Index Terms: Groundwater fluctuations, Kriging, interpolation, variance.

1 Introduction

Groundwater is a vital resource upon which life and livelihoods depend. Groundwater levels are observed though observation wells. The observatory systems aim to achieve a regional groundwater management policy and provide a regional picture of groundwater levels with emphasis on the existing situation. Groundwater level monitoring networks involve discontinuous sampling on variables with spatial continuity and highly skewed frequency distributions. Kriging can be used to estimate the variable sampled and provide a standard error of the estimate.

Kriging, a geostatistical interpolation technique, has become a widely used tool for estimating groundwater levels and other hydrogeologic properties. Its popularity stems from its ability to account for the spatial autocorrelation of data, resulting in more accurate and unbiased estimates compared to traditional methods like inverse distance weighting. The use of kriging for groundwater studies can be traced back to the 1970s, with pioneering work by [1], [2] and [3]. These early studies demonstrated the potential of kriging for mapping groundwater levels, highlighting its advantages over simpler interpolation methods. Kriging consistently outperforms these methods in terms of accuracy and reliability, particularly when dealing with data exhibiting spatial autocorrelation

Geostatistical methods have been implemented for observing groundwater levels and water quality parameters. This is, in turn, helpful in analyzing the spatial and temporal variability of groundwater depth. Groundwater level monitoring networks involve discontinuous sampling on variables with spatial continuity and highly skewed frequency distributions. Ordinary kriging can be used to estimate the variable sampled and provide a standard error of the estimate. In a case study [4], the groundwater level network simulation in the Chaiwopu Basin, Xinjiang Uygur Autonomous Region, China is attempted. This study used 18 initial phreatic water observation wells and determined that the Gaussian model was the best for the variogram parameters.

Three kriging methods such as simple, ordinary, and universal kriging were found to give the best fit, with modified ordinary kriging being the most accurate. This has been validated in an analysis of temporal variation [7] in China. The Wuwei oasis in northwest China is experiencing a decline in groundwater levels due to overuse of irrigation water, and eight different interpolation methods were used to estimate the decline over a period of three years.

The spatial and temporal dynamics of groundwater levels within a semi-arid, hard-rock aquifer located in Western India is investigated using Kriging [9]. Monthly groundwater level data from 50 sites across the study area were analyzed over a 36-month period (May 2006 to June 2009, excluding 3 months) to identify spatial autocorrelation and variances. One of the studies from South-East Asia [10] focuses on analyzing the spatial variability of groundwater level changes in the Sylhet region in Bangladesh division from 2000 to 2015. Geostatistical methods, specifically ordinary kriging with cross-validation, are used to create water table maps for the study area.

Several such attempts to analyze the spatio-temporal variability of groundwater levels in the semi-arid and humid tropics of India have shown the importance of ordinary kriging method in depicting groundwater levels. Ordinary kriging was found to be the optimal method for interpolating groundwater levels for the region of Panipat district, Haryana. The integrated approaches are also adopted including rainfall data and the canal network, helped in better understanding the causes of declining groundwater trends in the central part of Panipat [5]. In another study [8] ordinary kriging is utilized in mapping the groundwater quantity and quality scenario in the National Capital Territory of Delhi, India. Ordinary kriging and indicator kriging were used to analyze the spatial variability of groundwater depth and quality parameters. The generated spatial variability and probability maps will assist water resource managers and policymakers in the development of guidelines for the management of groundwater resources in the study area.

The universal kriging is applied to the command area of canal irrigation projects in north-western India to map groundwater levels optimally by [6] Measured elevations of the water table in September 1990 at 143 observation sites in an area of 4500 km^2 were used to construct an omni-directional experimental semivariogram.

A study [11] on Kriging falling on the same region attempts Kriging on open well data set for Dakshina Kannada District of Karnataka. The fluctuation of groundwater levels with the terrain was the highlight of this study. This study adopted root square mean error as the accuracy estimate. This study focuses on analyzing and quantifying the impact of land use and land cover transformations on groundwater levels in Dakshina Kannada district, Karnataka. The objectives of this work are to collect the groundwater data for a small watershed- *Ujire Halla* and to perform kriging operation to understand groundwater profile to aid management practices at micro level.

2 STUDY AREA AND DATA

2.1 Study Area

The study area is Ujire Halla watershed, located in Ujire, a town near Dharmasthala, Belthangady taluk of Dakshina Kannada district, Karnataka, India. The *Ujire Halla* watershed is delineated with the help of Google Earth and ISRO's Bhuvan web portal. This work chose 25 well points within the watershed area of 2 square kilometers. This area includes two major roads of the town, the first road connects Ujire to Charmadi-a hamlet on the foothills of Western Ghats and the other road connects to Dharmasthala-a popular pilgrimage. This area consists of paved and unpaved areas including small plantations, shrubs and natural vegetation. This also has lands under cultivation in majority such as paddy, areca coconut and rubber. The average temperature in this region is 29.60 Celsius, and has an annual rainfall exceeding 3000 mm. The soil is mostly lateritic type, characterised by high iron and aluminium content. The texture of the soil varies from fine to coarse. The soil in valleys and intermediate slopes is rich in loam whereas in upper slopes it is much coarse in nature [12]. River Mruthunjaya a tributary of westward river Nethravathi is present within the vicinity of 1.5 km in the watershed.

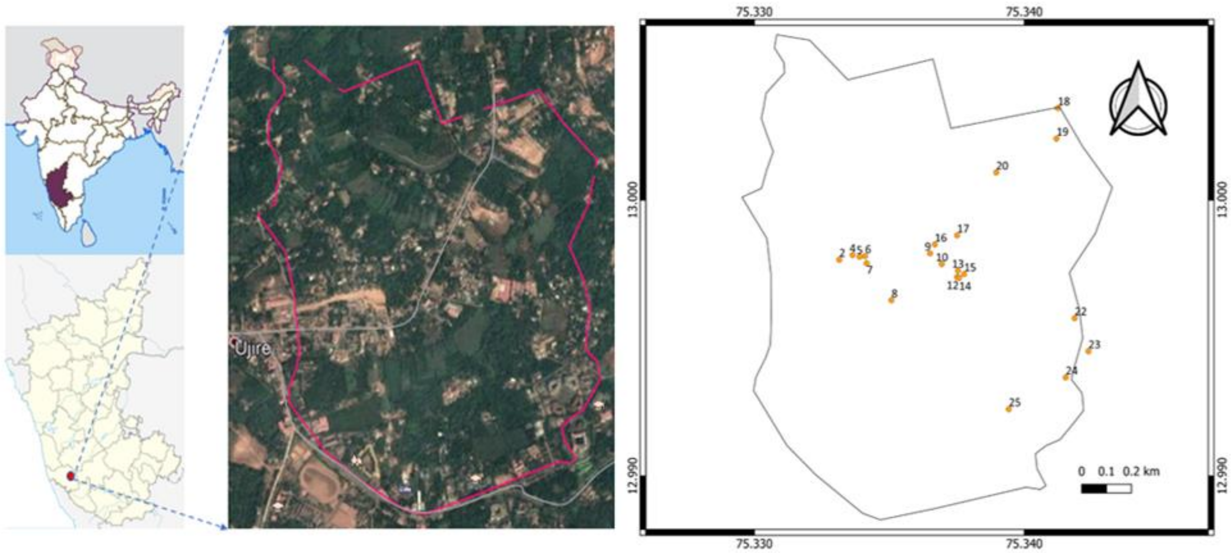

Fig.1. Study region-Ujire Halla watershed and the locations of observatory wells

A network of 25 open well points is selected from the initial reconnaissance survey. A detailed discussion on the sampler approach is explained in the next section.

2.2 Data

The well data were collected by rigorous field visits. Depth to groundwater level is observed using manual measurements with the help of a rope and weight.

Table 1. Well points

Well Point	X	Y	Depth of well (Feet)	Remarks
1	75.3329331	12.9975579	35	Shenoy (UN)
2	75.333143	12.997843	50	Rambo blocks
3	75.333418	12.997969	30	Abhishek (UN)
4	75.33364	12.998011	35	Shivagiri mess
5	75.333896	12.997948	35	KSRTC 1
6	75.3341	12.997972	25	Akilesh
7	75.334158	12.997708	25	Savitha teacher
8	75.335078	12.996371	40	SR bar opposite
9	75.336506	12.998072	35	Hotel Lavanya
10	75.336944	12.997685	35	Dip lecture
11	75.337108	12.997568	35	Zaffa juice point (UN)
12	75.337108	12.997213	40	Velangani
13	75.337108	12.997446	35	Badige mane
14	75.337108	12.99718	35	Anandha
15	75.337108	12.99732	40	Badige mane down
16	75.337108	12.998393	30	Halli mane opposite

17	75.337108	12.998725	35	Shravan Dhanvantri
18	75.337108	13.008033	35	Chinthan hostel
19	75.337108	13.002233	30	Anugraha opposite
20	75.337108	13.001002	35	Ranjith cement
21	75.337108	12.995511	30	Laxmi groups (UN)
22	75.337108	12.995722	30	Disha
23	75.337108	12.994525	35	Sumrudhikaveri
24	75.337108	12.993575	30	Shiva kripa
25	75.337108	12.992426	25	Sahana turn house
26	75.337108	12.989947	20	Panchami back side
27	75.337108	12.989724	35	Near Degree College
28	75.337108	12.990155	30	Near Degree College
29	75.337108	12.990194	20	Holla Arts

UN: data not collected

The first set of data was collected in the fourth week of November, second- and third-week data were collected in the first and second week of December, fourth week data was taken in the third week of January, fifth week data was collected in the third week of March and the final data was collected in the first week of April. The well point details are summarized in table1.

These well points are distributed evenly in the watershed to represent the whole area. To pre-process the data and analyse it further, the data has been categorized into four parts based on the directions in which they fall as shown in table 2.

Table 2. Direction of well points

Sl. No	Direction	No of wells
1	North-West	8
2	North-East	12
3	South-East	5
4	South-West	4

3 THE METHODOLOGY

After collecting all the data for six weeks, the corresponding range, average, standard deviation and variance were calculated. After the completion of statistical analysis, the Geo-statistical analysis was carried out using Quantum GIS (QGIS) software. The well data from the Excel sheet was exported to QGIS and then converted to shape files. These shape files were then subjected to Ordinary kriging operation. As a result, the Prediction map, Accuracy map and Quality measures were obtained. The overall methodology adopted is explained in fig. 2.

The steps involved are categorized into two stages: Pre-processing and Kriging. Pre-processing inspects for systematic and random errors associated with the measurement of groundwater levels. The data collected are in the intervals of twice in a month. Gauged groundwater level data were stored in Excel sheets and updated timely. The well points were divided according to their directions such as NE, NW, SE and SW using Google earth Satellite image. Once the pre-processing is done the data is ready for kriging.

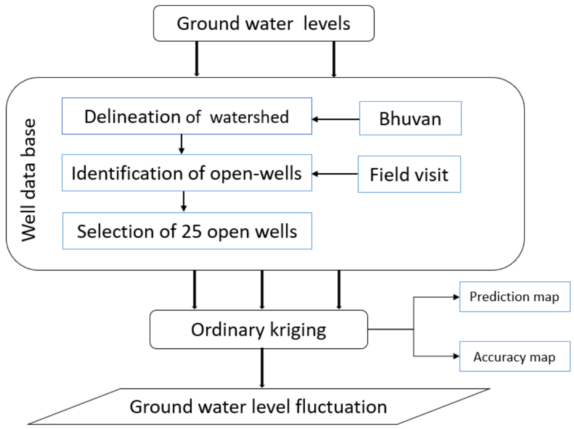

Fig.2. Methodology

Ordinary kriging is one of the methods of kriging employed to map the groundwater levels. The basic logics and formulations behind kriging are followed as mention in [13] and [14]. Ordinary kriging is performed using QGIS software. Kriging is an advanced geostatistical procedure that generates an estimated surface from a scattered set of points with z-values. Kriging assumes that the distance or direction between sample points reflects a spatial correlation that can be used to explain variation in the surface.

3 RESULTS AND DISCUSSIONS

3.1 Temporal groundwater fluctuation

Considering the data collected in Excel sheet and Ordinary kriging operation, six different groundwater fluctuations for six different weeks of all 25 well points were obtained. The water level fluctuation of November 2020 to April 2021 indicates that out of 25 wells analysed, 21 wells in the month of December (84%) are showing fall in water level. In the month of January 4 more wells were added to the existing 25 wells making a total of 29 wells for the study. In January, 4 (13.8%) wells are showing a rise in water level and 17 (58.62%) are showing a fall in water level. For the month of March, 24 (82.75%) are showing a fall in water level and 1 (0.03%) well is completely dry. In April, 1 (0.03%) well is showing a rise in water level, 22 (75.86%) are showing a fall in water level and 1 (0.03%) well is completely dry. By considering the above data it can be concluded that there is more fluctuation of water level in the month of January. The basic statistics utilized in understanding the overall groundwater level fluctuations are given in table 3.

Table 3. Basic statistics of groundwater level fluctuations

In feet	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Range	18.6	18.25	17.9	17.6	18.8	17.7
Average	11.99	10.55	10.02	11.06	7.29	4.91
Std. Deviation	4.52	4.44	4.36	4.84	4.48	4.23
Variance	20.47	19.75	19.04	23.43	20.12	17.95

3.2 Kriging results

The interpolated maps using Kriging for six-week durations are given in fig.3. By performing the kriging operation, it was possible to find the groundwater level and the fluctuation of water level in the selected watershed as discussed earlier. With the help of this sampled groundwater level data, it is possible to find the groundwater level of the surrounding areas where the level is unknown. Considering the direction of the watershed area one can say that the average depth of 7.3 feet from the ground level is observed on the North-East direction nearby Church Bus stand. Whereas in South-East direction, the groundwater level of south-west corner of watershed is 7.2 feet from the ground level. The groundwater

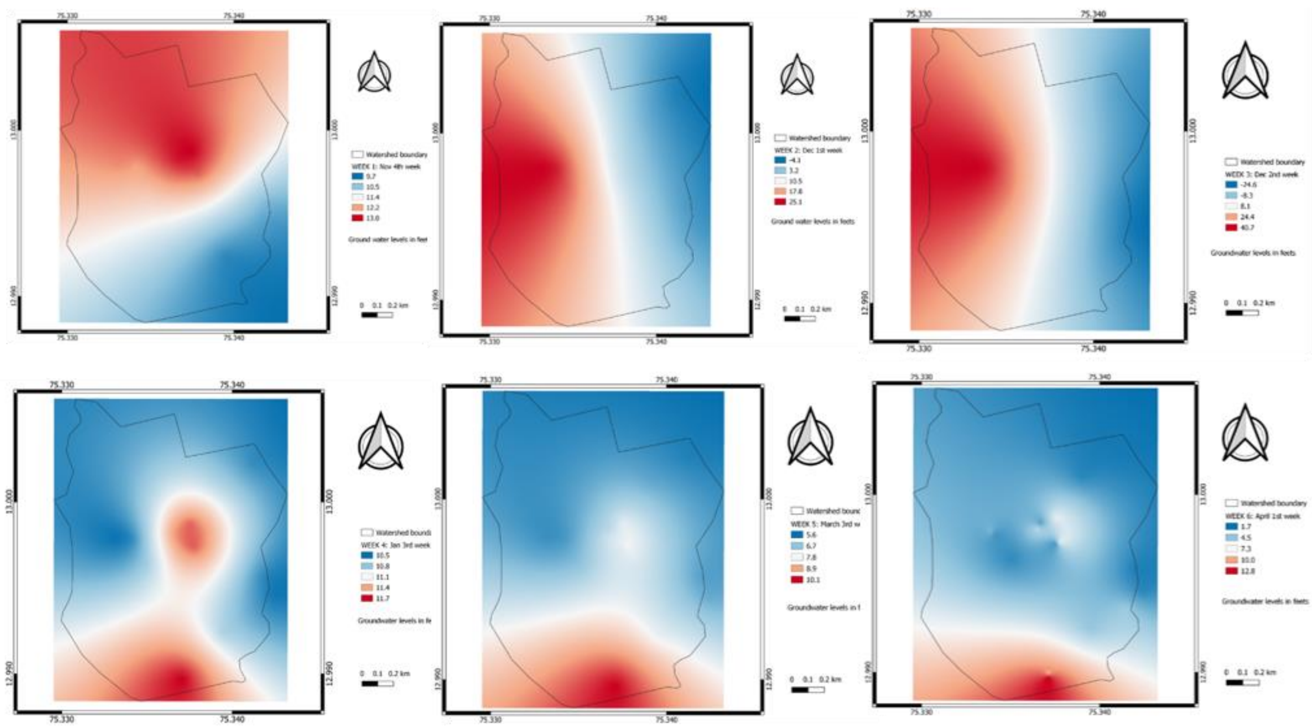

Fig. 3. Kriging Results for: a) fourth week of November b) First week of December c) Second week of December d) Third week of January e) Third week of March and f) First week of April

level near South-West direction is falling for about 13.7 feet from the ground level. In the NW direction, places nearby Kunjarpa-a village residing at the centre of the watershed, depicted groundwater levels as 13.5 feet from the ground level. These representations are the average of all six weeks data across the seasons, and the values can be more accurate if the number of well points is increased.

4 CONCLUSIONS

The salient conclusions drawn from the analysis of groundwater level data for a small agrarian watershed using ordinary kriging are listed below:

- Pre-analysis and geostatistical kriging have slight deviations in making the predictions. This is mainly due to the directional pattern available in ordinary Kriging;
- Fluctuations are minimum in the South East part of the watershed. However, the range of fluctuations observed in the watershed amounts 7.2 to 13.7 feet;
- Marked fluctuations are observed from the western zone of the *Ujire Halla* watershed and Kriging proves as one of the efficient mapping techniques for a small watershed such as this.

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