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Groundwater analysis and management plan using integrated community perception and geo-spatial techniques in Wana, South Waziristan

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Abstract

Groundwater is one of the most valuable natural resources supporting human health and economic development. Globally, there has been an enormous stress on groundwater. In Pakistan, water shortage and decreasing groundwater level is one of the major issues. The groundwater assessment and management study has been conducted in Wana, South Waziristan using field survey and geospatial techniques. To achieve objectives, both primary and secondary data sources were used. The secondary data were acquired from concerned governmental departments. Primary data were collected through questionnaire survey, personal observations and Global Positioning System (GPS). Landsat ETM+ images were extracted to derive the land use land cover (LULC) of the area with four classes i.e., (Barren land, vegetation, built up and water bodies) through maximum likelihood (ML) technique. Soil map of the study area was digitized in Arc GIS 10.5. Inverse Distance Weighted (IDW) technique was applied to interpolate rainfall. Different parameters include rainfall analysis, land cover, soil group and geology were used to generate NRCS model. NRCS hydrological and watershed modeling were applied to calculate the estimation of surface runoff and stream network order. Forestation, check dams and embankments have been proposed in the management plan. The results show groundwater level in Wana has declined 13 feet in the last five years. There are multiple factors that led to water depletion. The groundwater level drops sharply in the areas where there are high population and where there is large agricultural land. The need of construction of large and small dams to maintain the cultivation of water intensive crops in Wana South Waziristan, which will be helpful in augmenting the groundwater level, stabilizing the climate and will also prevent the land from flooding. The results and findings of this study can assist researchers for future research and decision makers.

1. Introduction

The Groundwater is one of the most valuable natural resources supporting human health and economic development (Wang et al., 2020). Globally, there has been an enormous stress on groundwater. The over-exploitation of water resources is threatening the ecosystem (Khare et al., 2018; Harini et al., 2018). Unfortunately, the excessive use and mismanagement of groundwater resources have led to water shortages (Jackmen et al., 2016; Shen, 2015). The consequences of groundwater unsustainability are becoming evident and the concern is the maintenance of long-term yield from aquifers (Singh, 2013; Moore & Fisher, 2012). Groundwater extraction for agricultural and domestic uses in areas such as South Asia and other countries has depleted the aquifer system (Chatterjee et al., 2009; Amore, 2012).

Groundwater is poorly known and understood by the general masses and decision makers (Famiglietti, 2014). Globally, there has been an enormous stress on groundwater resources (Riemann et al., 2012). This stress has also been noted in Pakistan and specifically in Tehsil Wana, district South Waziristan. The local residents of Wana, South Waziristan use the water reservoirs for multi-purposes, i.e., irrigational purposes, domestic purposes, municipal uses, recreational purposes and fishing. This will help in the development of the local community (Zektser, 2004). The water availability fluctuates throughout the year. As the main source of income of the residents of the Wana is agriculture and horticulture therefore, it is imperative to store rainwater so that it can be used as a substitute for groundwater (Rahman & Parvin, 2009).

This research will address the following objective, to assess the spatio- temporal variation in groundwater table, to identify the groundwater recharging zones using NRCs hydrological model and finally to identify suitable sites for micro-level multipurpose dams.

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2. Method

In the research both primary and secondary data sources were used to achieve the desired objectives. The secondary data were acquired from concerned government departments and other private organizations. Primary data were collected through questionnaire, personal observations and Global Positioning System (GPS). Prior to field survey, field visits and meeting with local people were arranged to understand the problem of declining groundwater. Based on the initial visits, micro- level investigations and analysis of the severe affected areas were carried out.

Global positioning system (GPS) was used to acquire the geo-location of the well, the respondents and the distance between points.

Following software was used for this purpose, Google Earth, Arc GIS 10.1.

2.1. Watershed Modelling

Stream network was created within the watershed of study area. Stream and watershed lines throughout the entire watershed were determined. Different streams orders were generated to propose potential sites for construction of check dams and embankments.

Surface run-off depth (mm) was estimated by applying NRCS hydrological model and implemented in Arc GIS environment. The main inputs spatial layers in the NRCS hydrological model were land cover, hydrological soil group, and geology and rainfall pattern. Rainfall events (annul & monthly) of 29 years (1990-2019) were processed by applying Inverse Distance-Weighted Technique (IDW) to interpolate event rainfall. The CN value is extracted by combining hydrological soil groups and land cover spatial layers to quantify the surface run-off potential. The mathematical expression of NRCS hydrological model is shown in the Equation 1.

$$Q = \frac{(P - Ia)\ 2}{P - Ia} + S \qquad (1)$$

Where P is total rainfall (mm), Ia is initial abstraction, F is cumulative infiltration excluding Ia, Q is direct surface runoff (mm), S is potential maximum retention after rainfall begins. Ia is assumed to be correlated to S through the Equation 2.

$$Ia = 0.2\ S \qquad (2)$$

The maximum retention is further related to the soil and land cover condition of the processed study area through CN by the Equation 3.

$$S = \frac{25{,}400 - 25}{CN} \qquad (3)$$

Descriptive Statistical Analysis was performed on the data which was acquired primarily during field survey.

The management plan for groundwater has also been design in the study. Different input parameters were considered in designing the management plan. It includes rainfall analysis, land cover, soil group and geology of the study area. These input parameters were then put in GIS environment to generate NRCS model.

3. Results

3.1. Ground water Assessment

Age of water pumps installed is mentioned in (table 2). 41% water pumps were newly installed and 24.7% were installed the past 5 to 10 years. The remaining installed pumps are even older than 10 years which makes the percentage of the 32%.

Table 1. Age of water pump installation.

Serial No.	Categories	Frequency	Percentage
1	>5 Years	70	41.17
2	5-10 Years	42	24.7
3	>10 Years	58	32.11
	Total	170	100

Table 2. Capacity of water Pump.

Serial No.	Water Pump Capacity (Inches)	Frequency	Percentage
1	1	12	7.05
2	2	36	21.17
3	2.5	16	9.41
4	3	76	44.7
5	4	27	15.88
	Total	170	100

The data in Table 3 shows the diameter of the pipeline of the water pumps and the capacity of these water pumps. 44% pumps had the capacity of the 3 inches. 16% were having the 4 inches diameter of the pipe. 22% pumps were those which had the capacity of the only 2 inches. 9 % of the water pumps have the capacity of 2.5 inches and 7 % have 1 inches capacity which mostly falls in hand pumps category.

Table 3. Domestic Water Consumption.

Serial No.	Water Consumption Per-day (Liter)	Frequency	Percentage
1	<50	54	31.76
2	50-100	35	20.58
3	>100	81	47.64
	Total	170	100

Data in (table 4) is about the daily domestic water consumptions. It is evident from the tabular data that about half of the population had the daily domestic usage of more than 100 liters of water per day. The other percentage was 31% of the people who use the average water less than 50 liters. And the percentage of the people which lies in between 50 to 100 liters was 20%.

The agricultural data of the respondents reveals that majority of the population has the land ranging between 25 to 50 Kanals and that is about 40%. Remaining 25% had the agricultural land ranging less than 25 Kanals. And about $1/3^{rd}$ kept the land more than 50 Kanals (Table 5).

Table 4. Agricultural land of the respondents.

Serial No.	Land (Kanals)	Frequency	Percentage
1	<25	53	31.17
2	25-50	68	40
3	>50	49	28.82
	Total	170	100

Table 5. Groundwater pumping in the study area.

Serial No.	Groundwater Pumping	Frequency	Percentage
1	Electric Motor	102	60
2	Solar Pump	43	25.29
3	Tube well	17	10
4	Hand Pump	08	4.17
	Total	170	100

Table 6 describes the ground water pumping in the region. It is evident in the tabular data that majority of the pumps are electric pumps which makes 60%. The other major use is of solar pumps. Solar pumps make 26% of the total pumps in the region. 10% are the tube well. The data also reveals that hand pumps were only 4% and these hand pumps are mainly used for domestic purposes only.

Table 6. Community's perception regarding Groundwater level.

Serial No.	Decrease in Groundwater Level (Feet)	Frequency	Percentage
1	5	42	24.7
2	5-10	32	18.82
3	10-15	41	24.17
4	>15	66	38.82
5	Dried	07	4.11
	Total	170	100

Table 7. Groundwater Level Variations in Villages.

Village Nmae	Groundwater Level (Average)	Drop in Groundwater Level (Feet)	Average of drop
Speen Kalai	250	15	15
Tanaye	250	15	15
Tiarza	180	15-20	17.5
Wacha-Khwara	150	15-20	17.5
Mughalkhel-Kalai	150	5	5
Doag Village	120	10-15	12.5
Daabkot	170	5-10	7.5
Karikot	200	15-20	17.5
Sherana	270	10-15	12.5
Sheen-Warsak	350	10	10
Ghwa Khwa	300	10	10
Azam-Warsak	450	15-20	17.5
Sholam	370	5	5
Inzar	500	20	20
Total	265		13.03571

In Table 7, the community perception about groundwater level is mentioned in the statistical manner. 38% people were of the view that groundwater level has been decreased more than 15 feet. 24% people were of the view that the decrease in the groundwater level is between 10 to 15% and the other majority had the perception that decrease is only 5 feet.

Groundwater in Wana is decreasing because of several prevailing problems. First and foremost; there is inordinate dispersion of tube well that has excessive use and immensely impacted the groundwater. Second underscored reason is owing to climate change, there is less rainfall; water level has declined 13 feet in previous five years. The results show that there are multiple factors that led to water depletion.

3.2. Groundwater Management

Different input parameters were considered in designing the management plan. It includes rainfall analysis, land cover, soil group and geology of the study area. These input parameters were then put in GIS environment to generate NRCS model. Forestation, check dams and embankments have also been proposed in the management plan.

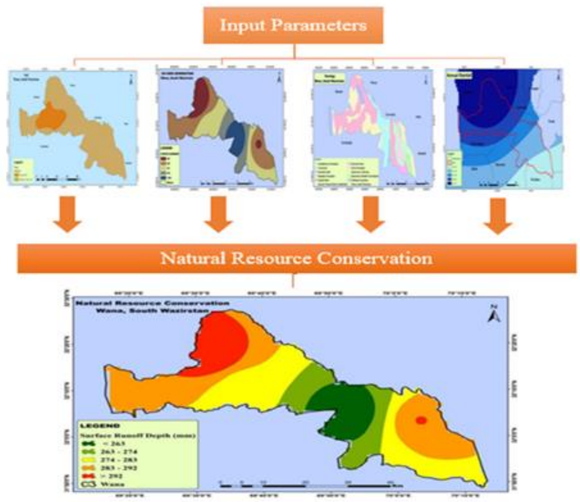

Figure 1. Flow Diagram of Natural Resource Conservation Service (NRCS)

3.3. Groundwater Management Plan

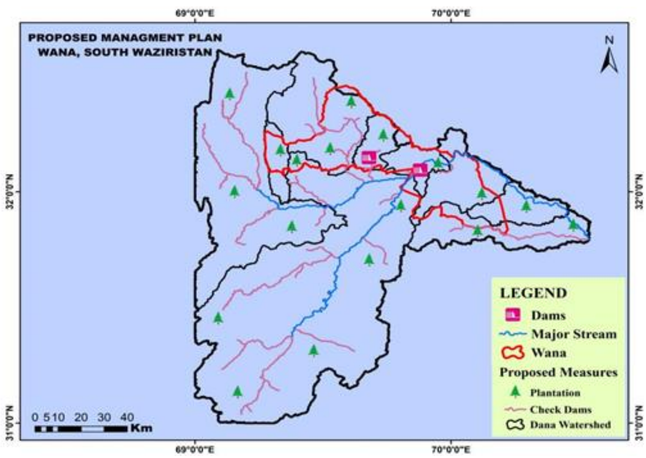

Figure 2. Groundwater management plan for Wana, South Waziristan.

The sustainability of groundwater is closely linked with some micro and macro management which influences land use and surface water and becomes one of the major challenges in natural resource management. Watershed management approach is basically used to manage groundwater. It is highly important to increases the retention capability of the watershed.

4. Discussion

Groundwater in Wana is decreasing because of several prevailing problems. First and foremost; there is inordinate dispersion of tube well that has excessive use and immensely impacted the groundwater. Second underscored reason is owing to climate change, there is less rainfall; water level has declined 13 feet in previous five years as mentioned earlier. The third reason is, as pointed out, is lack of government policy and inefficiency toward ground water management which severely affected the local people including their agriculture land. According to elders of the concerned region, the crop production has been decreased, and one of the indispensable issues is the migration of people, since when the water level started decreasing, many tribes migrated to other settled region to seek jobs as there are less or no water available in Wana to irrigate their own lands. It was also reported that the major tribe of Marwat had migrated in the past from Wana just because of water shortages. According to government institutions, they had and still have inadequate qualitative instruments for ground water to be measured. The lack of effective utilization of rainwater has put tremendous pressure on the groundwater. The over abstraction of groundwater for agricultural and domestic purposes has lowered the water table. It is found out from the study that during the past five years, the average drop in the groundwater level is 13 feet which means 2.6 feet drop per annum. It was also revealed from people perception that about 4 percent of the wells have dried completely in the last five years. Furthermore, the level of groundwater has lowered beyond the level of 550 feet in some areas. The most vulnerable areas to this declining groundwater in the study area are Azam Warsak, Sheen Warsak, Sholam and Inzar.

5. Conclusion

The study concludes that Wana is prone to the decreasing groundwater level. If the issue is not taken seriously, it will have dire consequences in the near future. The construction of small and medium reservoirs under the present conditions is the only possible way to meet the impeding water crisis. The construction of Dam will not only provide water for the agricultural activities but will also raise the groundwater level.

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