Assessment of Hydrological Potential for Installation of Dugwells: Development of Practical Methodology

M. Yasin, S. Ahmad, R. Roohi, R. Majeed, S.A. Hussain, A. Rehan and M.M. Ahmad

Abstract

Dugwells in Pakistan are open wells drawing their water mostly from shallow unconfined aquifers. Two common types of dugwells are: a) those located in consolidated formations (hard rock areas); and b) those located in unconsolidated formations.

Assessment of hydrological potential for siting of dugwells is difficult and complex due to the absence of contiguous aquifer in areas outside the canal commands. Normally, the dugwells are constructed to harvest shallow seepage water, which is usually recharged either by rainfall and/or seepage from the nearby streams. The assessment techniques were never developed nor tested for shallow seepage water to identify hydrological endowed areas. The Barani Village Development Programme under the component of Water Lifting Devices entered in a joint study with WRRI-NARC to develop hydrological mapping for selection of dugwell sites in six selected Tehsils of the Barani lands. Out of six Tehsils surveyed five Tehsils have dugwells constructed primarily by farmers. These Tehsils include Gujar Khan, Talagang, Attock, Jand and Pindi Gheb. Pind Dadan Khan Tehsil was excluded as most of the wells are either shallow tubewells or bore dugwells. The largest Tehsil is Gujar Khan comprising of 28 Union Councils and 369 villages, whereas Pindi Gheb is the smallest Tehsil comprising of 6 Union Councils and 70 villages. Talagang, Attock and Jand Tehsils comprise of 19, 14 and 12 Union Councils, respectively, with 91, 50 and 77 villages, respectively.

Considering the limitations associated with dugwell yield, other practical parameters were defined for the assessment of dugwells hydrological potential, which include: a) number of dugwells in a selected village; b) inner diameter of the dugwell; c) dugwell depth; d) minimum depth of water level from surface of the dugwell (wet season); and e) maximum depth of water level from surface of the dugwell (dry season).

Survey was based on the hydrological characterisation of the existing dugwells and then the classification criteria was used for the identification of potential zones having very-high to low potential hydrological endowments. In this study, Z-sum technique was used to observe the sensitivity of results for deriving the composite indicators. This technique was used for the assessment of dugwell hydrological potential in five selected Tehsils of the study area.

Maps of five selected Tehsils of the Pothwar plateau were using digitization facility available with Arc-Info software of the Geographic Information System. The digitized maps were fine-tuned to have error within acceptable and permissible limits. IDs were assigned to each village as the digitized base map includes the village boundaries within a selected Tehsil. The assessment criteria for dugwells hydrological potential based on five parameters (number of dugwells, inner diameter, dugwell depth, minimum and maximum depth of water level from surface of the dugwell) was used to develop standardise score for classification of the potential zones.

Results indicated that the Z-scoring technique could be used to reduce dimension of the multivariate problem associated with the construction of the composite indicator. The regression analysis indicated that dugwell depth and fluctuation in water level in the dugwell are the most essential parameters for assessment of the dugwells hydrological potential. These parameters are also an indirect measure of the sustained dugwell yield, which is essential for decision making to have sustained development of dugwells in any region. The paper provides simple and practical methodology, which can be adopted in Pakistan and elsewhere for characterisation and classification of dugwell hydrological potential.

INTRODUCTION

Traditional Dugwells

A dugwell consists of a pit dug to the aquifer or to the material where permeability is reasonable. The pit is often lined with masonry or pre-cast concrete rings to support excavation. Due to difficulty in digging below the water level, dugwells normally do not penetrate in the zone of saturation to a depth sufficient to produce high yield (Zuberi and Mc Whorter 1973).

Dugwells have been used for thousands of years but have become less popular with the advent of tubewells (Gibson and Singer 1969). The dugwells are usually shallow wells, generally less than 15 m in depth and several meters in diameter. In the past they were usually constructed by hand, and even today in many areas this is the principal method of construction (Israelsen and Hansen 1962; Koegel 1977). Today, interest in dugwells is reviving, and they still hold much promise for arid lands. Modern materials, tools, and equipment may transform crude holes in the ground, hosts for parasitic and bacterial diseases, into more safe, soundly engineered, hygienic, and reliable sources of water (Wagner and Lanoix 1959; Cembrowicz 1984). Dugwells are inexpensive and easy to construct and maintain by fairly unskilled labour. They provide storage for water, as well as a source (NAS 1974).

Well penetration depth and diameter are the main design parameters that influence the performance of the dugwell. The rate of pumping is much less responsive to changes in well diameter as compared to the changes in well penetration depth. It means that in a given aquifer, the well wetted perimeter has less contribution in increasing the yield of a dugwell as compared to the hydraulic gradient that exists between the water surface in the well and in the surrounding groundwater (Koegel 1977). Thus, the well penetration depth in relation to the aquifer characteristics is one of the important design parameter to achieve higher discharge rates.

Dugwells can be sunk only a few meters below the water table. This seriously limits the drawdown that can be imposed during pumping, which in turn limits the yield of the well. A dugwell that taps a highly permeable formation such as gravel may yield 0.6 to 2 lps or even more in some situations with only less than a meter drawdown. If the formation is primarily fine sand, the yield may be less than 0.6 lps. Because of their shallow penetration into the zone of saturation, many dugwells fail in times of drought when the water level recedes or when large quantities of water are pumped from the wells (USDHEW 1963).

In Afghanistan, Pakistan and India, dugwells are being seriously reconsidered (GOI 1962; NAS 1974). Since the use of rock drills became common, digging from formations that had blocked previous equipment has deepened many existing dugwells. In the last 25 years, Pakistan and India have also improved many dugwells solely by adding pumps. Powered by diesel engines or electric motors, inexpensive centrifugal or turbine pumps, installed on platforms 1-2 m above the water level, boost the water up to ground level. Suitable pumps are now made in many developing countries, including India and Pakistan.

Dugwells have contributed significantly in the rural development programmes of the Barani and arid regions of Pakistan, India and Sri Lanka. In Pakistan, several hundreds of dugwells were installed by the Second Barani Area Development Programme to provide water for rural communities to raise high value crops. The on-going Barani Village Development Programme has also included dugwells as one of the interventions. The project review had revealed that dugwell was one of the most promising interventions in the target area (ABAD 1998). In Madhya Pradesh, India, dugwell was one of the interventions of the integrated rural development programme, which helped the rural communities in raising their livelihood (NBARD 1994). In Sri Lanka, the Agrowell Programme was aimed to provide support to farmers to construct dugwells in the intermediate and dry regions of the country. There were serious concerns for the sustainability of dugwells based on aquifer characteristics and profitability of the cropping patterns (IIMI 1994).

Hybrid Wells

In Pakistan number of farmers have combined the dugwell concept with drilled bore, and such wells are named as dug-bore wells. These wells are of two types. The first type of dug-bore well consists of a drilled bore in the centre of the working dugwell, where both dugwell and bore contribute towards recharge. The second type of dugpit-bore well consists of a dug pit almost 1-2 m above the static water level and then bore is drilled to have an access to the aquifer. In this type of well only bore contributes for water, as pumping system is installed in the dug pit. The purpose is to reduce the suction lift of centrifugal pumps to keep the pumping cost as low as possible. Therefore, this type of well can be regarded as dugpit-bore well because the pit is dug purely for the purpose of reducing the suction lift. Bore drilled inside the working dugwell where both the dugwell and bore contribute towards recharge fulfils the definition of the hybrid well.

Dugpit-bore well system was adopted in India in early 70s, where farmers were drilling one or more bores inside their dugpits to modify these for getting higher discharges (20-24 lps). Generally, these bores had a depth ranging from 15-30 m, and centrifugal pump was major mode of extraction. However, this kind of modification reduced the life of the well from 15-20 years to only 5-7 years (Nagaraj 1994; Nagaraj et al 1999). This type of well is subjected to continuous lowering of bores with the lowering of water table. The WRRI-NARC has recently conducted some field surveys in the Toba Take Singh area, where farmers are lowering the bores after every 4-5 years or even earlier in the un-commanded area. Most of the time farmers have to abandon the dugpit-bore well for purpose of lowering and they prefer to dig the pit and drill the bore at a new site.

Skimming Dugwells

Extraction of fresh groundwater from an aquifer is desired to be at minimal cost. Furthermore, such extractions should not exhaust or ruin this groundwater resource for future use. Similarly, local customs and traditions for extracting groundwater should be given full consideration. In this context, dugwell may provide a simple, cost-effective, and traditionally familiar option as compared to other potential options for skimming fresh groundwater from fresh and brackish groundwater aquifers (Zuberi and McWhorter 1973).

Skimming dugwells provide the only source of fresh groundwater in areas like Sindh province, brackish groundwater zone in the Southern Punjab, Southern NWFP and parts of Balochistan provinces, where thickness of fresh groundwater is less than 15 m. In these areas tubewells cannot provide fresh groundwater because the deep groundwater is brackish and the salinity ranges between 1500-4000 ppm. Furthermore, dugwells can also provide an effective way of managing waterlogged areas, where concept of horizontal galleries or radial well points can be introduced to increase the recharge rate. WRRI-NARC has tested the concept of horizontal galleries at the Tropical Plants Introduction Centre, Karachi and Thana Boula Khan, to increase the yield of fresh groundwater.

Northwest India has large areas of land under irrigation from the Bhakra and Yamuna canal systems, but these areas are under severe constraints of low surface slopes, ineffective subsurface drainage and rising water table. Drainage options (subsurface drainage or skimming wells) are being considered for areas with shallow groundwater. Hybrid Eucalyptus with shallow rooting depth and varying water uptake levels is being considered as a biological management drainage measure and additional source of income (Diwan 1997).

Dugwells in Pakistan and Assessment of Hydrological Potential

Dugwells in Pakistan are open wells drawing their water mostly from shallow unconfined aquifers. The two common types of dugwells are: a) those located in consolidated formations (hard rock areas); and b) those located in unconsolidated formations (Ahmad 1976).

Consolidated underground formations usually known as hard rock areas are normally outside the Indus basin especially in the sub-mountainous and mountainous regions. The shallow groundwater reservoir is the only source of limited supplies of groundwater in these areas, in the absence of any deeper aquifers. The aquifer is dependent on precipitation for recharge and as such water table is prone to considerable fluctuations in relation to the incidence of rainfall. Due to poor permeability of consolidated formations, bore dugwells or tubewells are usually unsuitable in such formations. It is therefore, desirable in such formations to have dugwells capable of storing fairly large supplies of water during a given period. Thus, the available supplies of water can be obtained at small drawdown in relatively short periods, thereby allowing for sufficient recuperation periods between successive periods of pumping. Dugwells also expose a greater surface even of the aquifer for increased inflow.

Dugwells in the Indus basin are normally constructed in unconsolidated formations. The depth is normally 5 to 10 m below the static water level and dug in the dry period. The open excavation is usually circular in shape, the diameter varying from 1.5 to 4.5 m. The well in general derives water from unconfined aquifers. Their large diameters permit the storage of large quantities of water.

Dugwells in unconsolidated formations are usually provided with lining to prevent cave in of the walls. The common materials used for lining are brick, stones laid in cement mortar or pre-cast concrete rings. To make the design safe in case of drought, it is assumed that the well is empty and there is no internal pressure acting on it.

Assessment of hydrological potential for siting of dugwells is difficult and complex due to the absence of contiguous aquifer in the Barani lands. Normally, the dugwells are constructed to harvest shallow seepage water, which is usually recharged either by rainfall and/or seepage from the nearby streams. The review of literature indicated that assessment techniques were never developed nor tested for shallow seepage water to identify hydrological endowments. Barani Village Development Programme under the component of Water Lifting Devices entered in a joint study with WRRI-NARC to develop hydrological mapping for selection of dugwell sites in six selected Tehsils of the Barani lands. The survey was based on the hydrological characterisation of the existing dugwells and then the classification criteria was used for the identification of potential zones having very-high to low potential hydrological endowments.

The paper provides simple and practical methodology, which can be adopted in Pakistan and elsewhere for characterization and classification of hydrological potential for dugwells.

METHODOLOGY

Location and Study Area

The study area is located in the Pothwar plateau of the Barani lands covering area between rivers Indus and Jehlum. The Pothwar plateau consists of sub-mountainous region with severely eroded loess soils. The cultivated area is around 1.0 million ha. Six Tehsils were selected where Barani Village Development programme is being implemented by ABAD. Out of six Tehsils surveyed five Tehsils have dugwells constructed primarily by farmers. These Tehsils include Gujar Khan, Talagang, Attock, Jand and Pindi Gheb. Pind Dadan Khan Tehsil was excluded, as most of the wells are either shallow tubewells or dug-bore wells.

The largest Tehsil is Gujar Khan comprising of 28 Union Councils and 369 villages, whereas Pindi Gheb is the smallest Tehsil comprising of 6 Union Councils and 70 villages. Talagang, Attock and Jand Tehsils comprise of 19, 14 and 12 Union Councils with 91, 50 and 77 villages, respectively.

Distribution of Dugwells in the Study Area

The distribution of dugwells in selected five Tehsils varied significantly, as the number of dugwells were 469 and 886 for Pindi Gheb and Gujar Khan Tehsils, respectively, which also represent smallest (6 Union Councils) and largest (28 Union Councils) Tehsils of the study area. Largest numbers of dugwells were in the Talagang Tehsil (19 Union Councils) having 1691 dugwells.

Table 1. Distribution of dugwells in selected five Tehsils of the Study Area.

Name of Tehsils	Union Councils	No. of Villages with dugwells	No. of Villages with no dugwells or missing data	Total Villages	No. of Sampled Wells
Gujar Khan	28	216	153	369	886
Talagang	19	67	24	91	1691
Attock	14	50	0	50	696
Jand	12	77	0	77	945
Pindi Gheb	6	18	52	70	469
Total	79	428	229	657	4687

In Attock and Jand Tehsils, numbers of dugwells were 696 and 945, respectively (Table 1). In total 4687 dugwells were surveyed in the selected five Tehsils. Thus the sample size was considerably large for development of practical methodology for the assessment of dugwells hydrological potential.

Criteria for Assessment of Dugwells Hydrological Potential

Characterisation Criteria

Characterization of dugwells hydrological potential is a complex issue, as parameters related to dugwell yield cannot be easily measured. The dugwell yield varies significantly due to the dry and wet periods, proximity to the recharge source and recharge to the dugwell. Therefore, it was not possible to have information regarding dugwell yield due to the absence of any contiguous and regular aquifer in the study area.

Considering the limitations associated with dugwell yield, the following practical parameters were defined for the assessment of dugwells hydrological potential:

- Number of dugwells in a selected village;
- Inner diameter of the dugwell;Dugwell depth;
- Minimum depth of water level from surface of the dugwell (DW_{min});
- Maximum depth of water level from surface of the dugwell (DW_{max}).

The inner diameter and depth of dugwells are the two indicators, which describe the potential dugwell yield. The difference between DW_{max} and DW_{min} describes the variation in depth of water column and thus serves as an indirect indicator for the potential dugwell yield. The maximum and minimum depths of water column can be estimated using the following relationship:

$$DWC_{max} = D_{well} - DW_{min}$$

$$DWC_{min} = D_{well} - DW_{max}$$

Where

DWC_{max} =maximum depth of water column in the dugwell, feet;

DWC_{min} =minimum depth of water column in the dugwell, feet;

D_{well} =depth of dugwell, feet;

DW_{min} =minimum depth to water level from surface of the dugwell, feet;

DW_{max} =maximum depth to water level from surface of the dugwell, feet.

Classification Criteria and Mapping

Classification of dugwells hydrological potential is a complex phenomena dealing with multivariate problem of indicators to standardize the score for classification of the potential. However, a practical approach having physical significance was developed to have understanding of the classification criteria. For example, if the number of dugwells is less, dugwell diameter is smaller, dugwell depth is shallower and DW_{min} and DW_{max} are smaller, the dugwells hydrological potential will be higher. The highest values of these parameters would represent the lower potential. The problem associated with the standardization of the characterisation parameters can be taken care through the adoption of Z-scoring technique. The classification of dugwell hydrological potential was based on the Z-sum values.

Collection of Dugwells Hydrological Data and Database Development

Questionnaire was designed to collect dugwells hydrological data from farmers of selected Tehsils alongwith some measurements at the time of survey. The questionnaire was pre-tested and adjustments were made accordingly. Questionnair includes additional information regarding pumping facility, cropping pattern, etc., which will be used for further analysis in future. The data of dugwells hydrological parameters collected were used to develop database for the selected Tehsils in Microsoft Excel Programme. After the completion of the database, missing values were identified and filled by using the trend of the nearby values. The missing values were less than 0.5%, which is less than the permissible limit.

Z-Scoring

In the literature on regional development, a number of techniques have been used to reduce the dimensions of the complex multivariate problem associated with the construction of composite indicator. The first-most commonly used is the **Z-sum technique,** which sums for a particular region (Tehsil) its Z-score on each indicator. The Z-score is the standardised score, which has zero mean and unit variance. The lower the Z-sum of a certain region, it is endowed with higher hydrological potential for dugwells. The Z-sum can be computed as follows:

$$(Z\ sum)_j = \sum_{i=l}^{i=n} Z_{ij}$$

Where

Z_{ij} = X_{ij}-X_i / S_i;

n = numbers of indicators;

X_i = mean value of the ith indicator;

S_i = Standard deviation of the ith indicator,

X_{ij} = Value of the ith indicator in the jth Tehsil.

In this study, Z-sum technique was used to observe the sensitivity of results with respect to the choice of technique for deriving the composite indicators. This technique was used for the assessment of dugwells hydrological potential in five selected Tehsils of the study area.

Digitisation of Base Maps

The maps of five selected Tehsils of the Pothwar plateau were digitized using digitization facility available with Arc-Info software of the Geographic Information System. The digitized maps were fine-tuned to have error within acceptable and permissible limits. IDs were assigned to each village as the digitized base map includes the village boundaries within a selected Tehsils.

RESULTS AND DISCUSSIONS

Distribution of Dugwells Characterisation Parameters

Number of dugwells per village was extremely variable in all the Tehsils. The highest variability was in the Talagang Tehsil where minimum and maximum number of dugwells varied as 1 and 513, respectively, with an average of around 25. The number of dugwells in a village was variable in other Tehsils with minimum-maximum range of 1-35, 1-64, 1-119 and 2-121 in Gujar Khan, Attock, Jand and Pindi Gheb Tehsils, respectively. The average number of dugwells in a village was also variable in other Tehsils with 4, 14, 12 and 25 in Gujar Khan, Attock, Jand and Pindi Gheb Tehsils, respectively. The higher variability in number of dugwells is a good indicator of heterogeneity in availability of shallow seepage water (Table 2).

Minimum diameter of dugwells of 3 feet and maximum of 15 feet was observed in the Gujar Khan Tehsil, with an average of 8 feet. The diameter of dugwells was variable in other Tehsils with an average of 11 feet in Talagang, Attock, Jand and Pindi Gheb Tehsils. The average dugwell diameter in Talagang, Attock, Jand and Pindi Gheb Tehsils was almost same indicating less variability compared to the Gujar Khan Tehsil, where lowest minimum dugwell diameter of 3 feet was observed. The lowest and highest dugwell depths of 13 and 107 feet were observed in the Gujar Khan Tehsil with an average of 42 feet. The average well depths of 48, 42, 46 and 37 feet were observed for Talagang, Attock, Jand and Pindi Gheb Tehsils, respectively. The average dugwell depth in most of the Tehsils varied between 40-50 feet (Table 2).

The minimum depth to water level from surface of the dugwell (representing the wet season) varied in different Tehsils where average depth of 8, 10, 11, 6 and 12 feet was observed for Gujar Khan, Talagang, Attock, Jand and Pindi Gheb Tehsils, respectively. The maximum depth of water level from surface of the dugwell (representing the dry season) varied in different Tehsils where average depth of 25, 14, 15, 12 and 14 feet was observed for Gujar Khan, Talagang, Attock, Jand and Pindi Gheb Tehsils, respectively. The highest variability was observed in Gujar Khan Tehsil compared to other Tehsils (Table 2).

Table 2. Dugwells hydrological parameters in villages of Selected Tehsils in the Study Area.

Name of Tehsils	Parameters	Characterisation Parameters in Selected Villages				
		No. of Wells	Well Diameter (ft)	D_{well} (ft)	DW_{min} (ft)	DW_{max} (ft)
Gujar Khan	Minimum	1	3.00	13.00	1.38	6.67
	Maximum	35	15.00	107.00	32.00	89.00
	Average	4	7.99	41.69	8.00	24.55
	Std. Deviation	5.46	1.71	17.92	5.26	12.92
	C.V	133.07	21.40	42.98	65.68	52.65
Talagang	Minimum	1	9.00	18.00	2.63	6.00
	Maximum	513	13.50	116.00	20.11	27.75
	Average	25	10.75	47.56	9.51	14.45
	Std. Deviation	62.80	0.85	20.63	4.60	5.07
	C.V	248.83	7.91	43.37	48.34	35.08
Attock	Minimum	1	10.00	30.33	8.00	12.00
	Maximum	64	12.28	76.00	16.00	20.00
	Average	14	11.42	42.42	10.68	14.61
	Std. Deviation	12.54	0.59	7.97	2.44	2.44
	C.V	89.57	5.13	18.79	22.84	16.70
Jand	Minimum	1	6.00	18.19	1.00	4.50
	Maximum	119	20.00	110.00	14.48	22.00
	Average	12	11.22	46.25	6.02	12.35
	Std. Deviation	20.66	2.47	16.60	3.76	4.47
	C.V	168.32	22.00	35.90	62.42	36.21
Pindi Gheb	Minimum	2	10.24	23.44	8.09	10.11
	Maximum	121	12.23	69.60	14.00	16.13
	Average	25	10.98	37.46	12.42	14.49
	Std. Deviation	28.01	0.58	10.38	1.99	1.94
	C.V	112.02	5.31	27.70	16.04	13.36

D_{well} –Dugwell depth from land surface; DW_{min} –Minimum depth to water level from surface of dugwell and DW_{max} –Maximum depth to water level from surface of the dugwell

Cumulative Assessment of Dugwells Hydrological Potential

Z-scoring of all the parameters was conducted to have stndardized score for the dugwells hydrological potential zones. Z-sum represents the cumulative score of all the parameters selected for characterization of the potential. As an example the distribution of Z-sum for Gujar Khan is plotted in Figure 1, where values of score varied from -6.59 to 11.15. The distribution indicated that there were more –ve values compared to +ve values. Thus the distribution was slightly skewed. The distribution of Z-Sum values was classified in four classes representing values for very high (< -3.0), high (-3.0 to 0), medium (0.01 to 3.0) and low (> 3.0). The limits were selected considering the slope of values within a class. These limits were also used for Talagang and Pindi Gheb Tehsils. Similar approach was used to describe class limits for Attock (very high < -2.5, high – 2.5 to 0, medium 0.01 to 2.5, and low > 2.5) and Jand (very high < -2.0, high –2.0 to 0, medium 0.01 to 2.0, and low > 2.0) Tehsils (Table 3).

Figure 1. Distribution of Z-Scoring to assign ranks for classification of dugwell hydrological potential in Gujar Khan Tehsil of the Study Area.

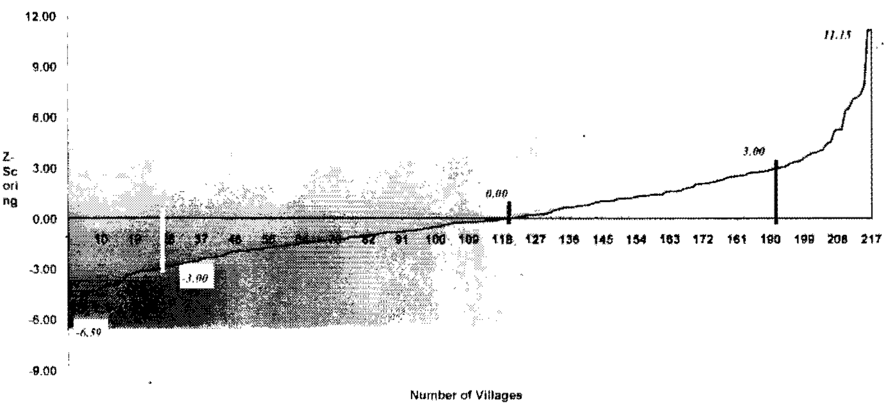

Table 3 Classes and limits of Z-Sum for classification of dugwells hydrological potential.

Class	Limits of Z-Sum Values For Selected Tehsils		
	Gujar Khan, Talagang and Pindi Gheb	Attock	Jand
Very High	< – 3.00	< -2.50	<- 2.00
High	-3.00 – 0.00	-2.50 – 0.00	-2.00 – 0.00
Medium	0.01 – 3.00	0.01 – 2.50	0.01 – 2.00
Low	> 3.00	>2.50	> 2.00

Dugwells Hydrological Potential Maps

Based on the hydrological potential classes (very high, high, medium and low), ranks were assigned for mapping using Arc-Info GIS software. Maps of dugwells hydrological potential were prepared which can be used as an indicator for selection of sites for further development of dugwells in the Barani Village Development Project.

Distribution of Dugwells Hydrological Potential Zones

Map prepared for the Gujar Khan Tehsil is presented in Figure 2. Distribution of area under each potential zone was computed using the Arc-Info GIS software. Similar exercise was made for rest of the four Tehsils (Table 4). The majority of Tehsils are having more than 60% area under medium and low potential zones and over 20% area under high potential zone. Pindi Gheb Tehsil was different than the others as hardly 8.5% area was classified having very high to high potential. Thus there is significant variability in hydrological potential of all the five Tehsils. Tehsil Jand is endowed with better hydrological potential compared to other Tehsils.

The hydrological potential maps would certainly help to improve the decision making process for the selection of dugwell sites. The variability in space further demands that these maps should be used as first approximation and more information must be collected to document the localised conditions.

Table 4. Distribution of dugwells hydrological potential zones in Selected Tehsils of the Study Area.

Tehsil	Area under each Potential Zone (%)			
	Very High	High	Medium	Low
Gujar Khan	4.0	23.7	33.1	39.2
Talagang	5.3	29.5	38.0	27.2
Attock	6.2	20.3	39.4	34.1
Jand	35.8	20.0	35.1	9.2
Pindi Gheb	2.2	6.1	20.4	71.3

Evaluation of Potential Assessment Criteria

Correlation of Parametric Analysis

Dugwells diameter was slightly correlated to the well depth, however, the correlation was higher in Attock, Jand and Pindi Gheb Tehsils compared to other Tehsils.

Depth of well was strongly correlated with fluctuation in water level in the dugwell (DW_{min} and DW_{max}). The parameters of DW_{min} were highly correlated with DW_{max} (Table 5).

This correlation was a good indicator that fluctuations in water level are the most essential parameter in the assessment of dugwells hydrological potential. However, the parameter is also affected by the extreme events of droughts and floods.

Table 5. Correlation analysis of dugwells hydrological characterization parameters for Selected Tehsils in the Study Area.

Name of Tehsils	Correlation	Dugwells Characterisation Parameters			
		Well Diameter (ft)	D_{well} (ft)	DW_{min} (ft)	DW_{max} (ft)
Gujar Khan	No. of Wells	0.12	-0.25	-0.18	-0.23
	Well Diameter		-0.12	-0.02	-0.12
	D_{well}			0.48	0.84
	DW_{min}				0.56
Talagang	No. of Wells	0.01	0.05	-0.13	0.10
	Well Diameter		-0.12	0.10	0.03
	D_{well}			0.64	0.69
	DW_{min}				0.87
Attock	No. of Wells	-0.14	-0.22	0.06	0.02
	Well Diameter		0.18	0.20	0.26
	D_{well}			0.44	0.46
	DW_{min}				0.98
Jand	No. of Wells	0.11	-0.24	0.40	0.33
	Well Diameter		-0.45	0.18	0.20
	D_{well}			-0.27	-0.27
	DW_{min}				0.92
Pindi Gheb	No. of Wells	0.02	-0.39	-0.35	-0.34
	Well Diameter		0.13	-0.16	-0.19
	D_{well}			0.52	0.49
	DW_{min}				0.997

D_{well} –Dugwell depth from land surface: DW_{min} –Minimum depth to water level from surface of dugwell and DW_{max} –Maximum depth to water level from surface of the dugwell

The depth of water level data (DW_{min} and DW_{max}) was available in all the Tehsils. The average depth to water level ranged between 8-25, 10-14, 11-15, 6-12, 12-14 feet for Gujar Khan, Talagang, Attock, Jand and Pindi Gheb Tehsils, respectively. Gujar Khan Tehsil showed higher level of variability and thus water level fluctuates more than other Tehsils, therefore relatively low correlation of 0.56 was observed between the two water levels for the Gujar Khan Tehsil. The wide variability in all the five hydrological parameters indicated the need for standardizing the score of the parameters for having better assessment of the hydrological potential.

Regression of Characterisation Parameters

Based on the results of the correlation test, regression analysis was carried out for three selected parameters like well depth, DW_{min} and DW_{max}. The regression analysis indicated that R^2 values of DW_{min} and DW_{max} were 0.32, 0.75, 0.96, 0.84 and 0.99 for Gujar Khan, Talagang, Attock, Jand and Pindi Gheb Tehsils, respectively (Table 6). This higher value of R^2 is a good indicator that fluctuation in water level is the most essential indicator for assessment of dugwells potential in any region.

The physical significance of the parameter is that if the fluctuations in water level are smaller during wet and dry seasons, the more reliable development of dugwells is possible. Thus there is a need to conduct further surveys of few selected dugwells, to indicate the seasonality and spatial and temporal variations in water levels in the dugwells. This is an important research objective and requires long-term studies, but huge resources are required to initiate such studies.

Table 6. Regression analysis of dugwells hydrological characterization parameters of selected Tehsils in the Study Area.

Name of Tehsils	Parameters	R^2	Intercept	Slope
Gujar Khan	D_{well} Vs DW_{min}	0.235	2.080	0.142
	D_{well} Vs DW_{max}	0.710	-0.784	0.608
	D_{min} Vs DW_{max}	0.318	13.446	1.387
Talagang	D_{well} Vs DW_{min}	0.410	2.723	0.143
	D_{well} Vs DW_{max}	0.476	6.384	0.170
	D_{min} Vs DW_{max}	0.753	5.350	0.957
Attock	D_{well} Vs DW_{min}	0.191	5.014	0 134
	D_{well} Vs DW_{max}	0.211	8.641	0.141
	D_{min} Vs DW_{max}	0.961	4.136	0.981
Jand	D_{well} Vs DW_{min}	0.073	8.850	-0.061
	D_{well} Vs DW_{max}	0.075	15.771	-0.074
	D_{min} Vs DW_{max}	0.842	5.776	1.093
Pindi Gheb	D_{well} Vs DW_{min}	0.274	8.653	0.100
	D_{well} Vs DW_{max}	0.242	11.048	0.092
	D_{min} Vs DW_{max}	0.993	2.455	0.969

Reliability of Hydrological Potential Assessment Criteria

Reliability of the assessment criteria has to be seen in the context of having either no information or some information for the dugwells. At present, there is hardly any information available for dugwells in the country rather in the region. Therefore, the assessment criteria developed for the dugwells hydrological potential must be viewed in the context of practicability of mapping and use of information for further development of dugwells.

The criteria of five parameters seem reasonable and can be refined further based on the field evaluation by the development agencies. The most essential parameter of dugwell depth and fluctuations in water level are included in the assessment criteria, therefore reliability is reasonably high.

CONCLUSION

The assessment criteria for dugwells hydrological potential based on five parameters (number of dugwells, inner diameter, dugwell depth, minimum and maximum depth to water level from surface of the dugwell) was successfully used to develop standardise score for classification of the potential zones. Z-scoring technique can be used to reduce dimension of the multivariate problem associated with the construction of the composite indicator. The regression analysis indicated that dugwell depth and fluctuation in water level in the dugwell are the most essential parameters for assessment of the dugwells hydrological potential. This parameter is also an indirect measure of the sustained dugwell yield, which is essential for decision making to have sustained development of dugwells in any region.

RECOMMENDATIONS FOR FURTHER REFINEMENT

The hydrological potential for installation of dugwells is an element for decision-making in selection of sites for dugwells. Therefore the maps developed under the subject study will be used by the development agency. The users' would certainly identify limitations associated with the maps and the assessment criteria. Based on field validations through actual use of the maps would help to further fine-tune the assessment criteria and mapping methodology. However, the research teams are recommended to collect further information on spatial and temporal variability of water level in dugwells through initiating a long-term research study.

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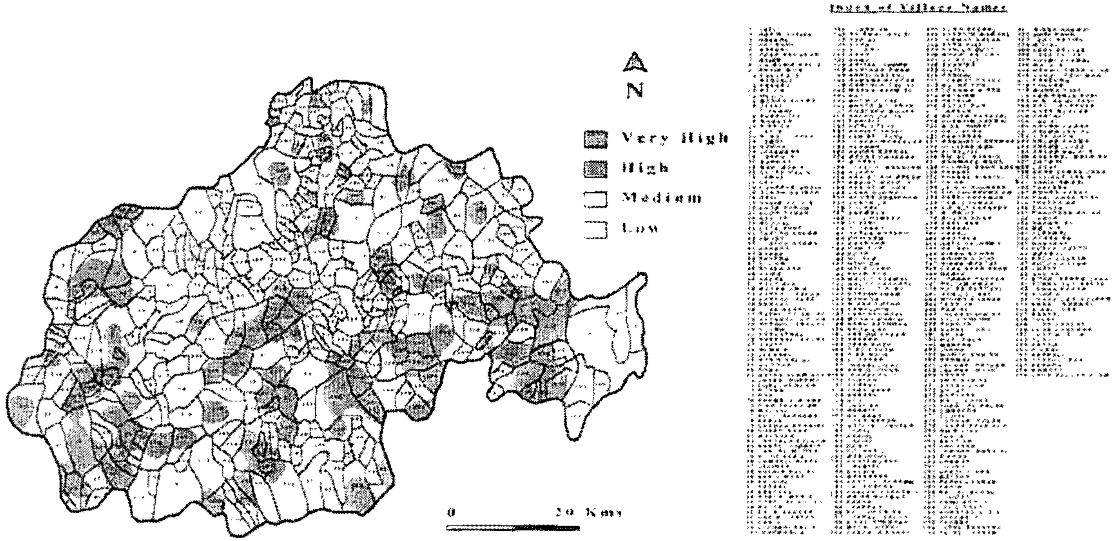

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