Computational water management strategy of Tlawng River Basin using geo-informatics

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ABSTRACT

Aizawl city is experiencing seasonal water scarcity. Tlawng is the longest River in Mizoram which flows for about 234 km length in Mizoram in south - north direction and joins the River Barak in Cachar district of Assam state. As Tlawng River is close to the Aizawl city, it will be wise to make some safe and durable strategy for storing rain water safely in predefined reservoirs and use it during hour of needs for domestic and agricultural purposes. In fact, Aizawl city is located within the Tlawng River basin at an average elevation of about 1,200 metres above mean sea level. An attempt has been made in this study for identification of feasible sites for construction of water reservoirs at appropriate locations based on the integration of thematic data on slope, flow accumulation, lithology, drainage density, lineament density and lineament direction using the advanced tools of ArcGIS software. Thirty two ideal sites have been identified in the vicinity of Aizawl city based on the multi-criteria evaluation of the thematic layers.

Keywords: Flow accumulation, Flow direction, Geo-informatics, Reservoirs, Thematic data

1. Introduction

Water management refers to the judicial use of water resources with an objective to minimize the wastages. India receives huge amount of rainfall during rainy season that often leads to floods causing damage to human habitations, property and sometimes loss of life [1]. In fact, worldwide investigations on water management system has become an important issue since water is an essential resource for the survival of all forms of life and it is going to be scarce day by day. Good water management refers to implementation developmental strategies to store excess water that can be utilized during lean period. Rain water can be harvested during rainy season at suitable locations in and around the catchment which can be used during its scarcity [2]. The point of investigation here is storing the excess water at suitable locations causing minimum damage to ecosystem and maintaining safety. The present study deals with such a problem focussing on a water starved region namely Aizawl, the capital of Mizoram.

The stored water thus collected can be brought to Aizawl through interconnected stream network of the Tlawng River. This strategy is expected to reduce the chances of flooding and drought in this region as happened several times in the past. The Tlawng River during the past decade had caused flood induced disaster within the vicinity of Aizawl city and hence, water management has become inevitable. The present study is expected to resolve the water scarcity problem of Aizawl to a great extent.

Several methodologies have been employed for identification of suitable sites for the construction of reservoirs [3]. The most conventional method for identifying suitable dam site location is field survey owing to its several advantages. Yet, the primary drawback of this approach is that larger areas cannot be considered and the area for such a site requires the investigation of vast region, therefore inefficient. Highly accurate thematic layers can be generated using the high resolution satellite imagery [4, 5] and integrated with more precision using GIS software [6]. Computational analysis of this data by using the advanced techniques of geographical information systems will be helpful for the selection of sites in different site selection strategies. The present study is the first of its kind in this highly rugged terrain to identify the sites which are suitable for the construction of dams.
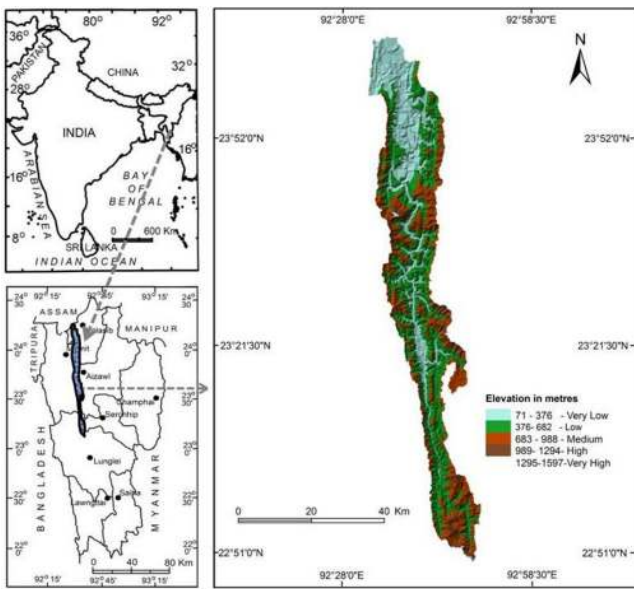
Fig. 1. Location map of the Tlawng River basin.

1.1. Description of the Study Area

The Tlawng River basin falls in parts of the districts namely, Kolasib, Mamit, Aizawl, Serchhip and Lunglei in Mizoram. It is a north – south aligned basin located between 92° 32' 10"-92° 50' 23" east longitudes and 22°49'58"-24°07'18" North latitudes spreads in an area of about 1,732.72 km^2 (Fig. 1). The River Tlawng originates in Zopuii hill near Zobawk village in Lunglei district at an elevation of about 1,395 m above MSL. The highest elevation of 1,597 is seen in the north-western part and the lowest elevation of 71 m at its mouth. The River flows in north direction over a length of about 234 km in Mizoram and joins the Barak River in Cachar district of Assam state. According to the watershed Atlas of India the Tlawng River basin code is 3C2A8. Tut and Teirei are the major tributaries to the Tlawng River. Sandstones, siltstones & shales, clayey sand, gravel, sand and silt are the major litho-units found in the basin of which sandstones, siltstones and shales spread extensively. The moist tropical type of climate prevails in this region with an average annual rainfall of about 250 cm. (Table S1).

2. Material and Methods

Topographical maps of Mizoram published by Survey of India have been used to delineate drainage network of the study area. Drainage density map has been prepared by using the formula of Horton [7]. Faults, fractures and lineaments have been identified on the geocoded satellite image of IRS P6 LISS IV MX (dated 21 February 2018) by visual interpretation and the lineament density has been computed. Land use/ land cover map has been prepared by visual interpretation using the satellite imagery and ground truth verification. ASTER GDEM has been downloaded from NASA website [8] and used to generate slope and flow accumulation

by using ArcGIS 9.3 software. Lithology map has been prepared from the geological map published by the Geological Survey of India with ground truth verification. Field investigation has been carried out to measure channel dimensions at selected sites along the Tlawng River. The thematic layers such as slope, lithology, flow accumulation, drainage density and lineament density have been integrated by multi-criteria evaluation using ArcGIS spatial analyst tools to identify suitable dam sites.

3. Thematic Data

3.1. Rainfall

Rainfall is the most important factor as the availability of ground water depends on it. The area receives an average rainfall of about 183 cm during the southwest monsoon period from June to September. The rainfall distribution is more or less uniform in the Tlawng River basin (Fig. 2). The southern most part receives high amount of rainfall which ranges between 2,500 and 3,000 mm whereas the western part receives less than 2,000 mm. Similarly, the northern most part receives above 2,500 mm of rainfall while in the central part it ranges between 2,000 mm and 2,500 mm. As a whole rainfall increases towards the southern part of the study area.
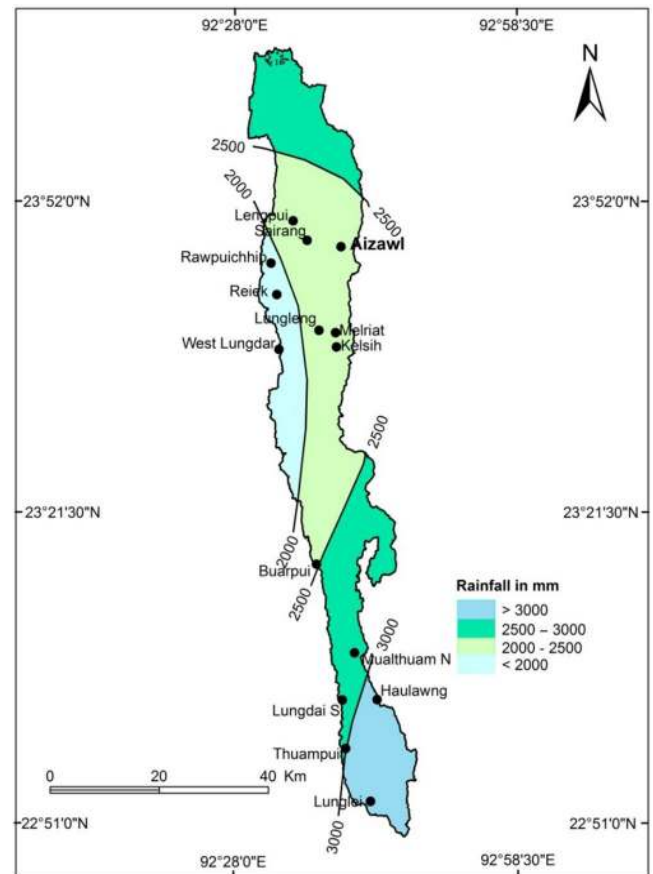

Fig. 2. Rainfall distribution in Tlawng River basin.

3.2. Slope

Slope is the major factor which controls infiltration, runoff and also the intensity of erosion. In fact, the runoff rate in Mizoram is higher than infiltration due to nature of the rock and mostly by steepness of the terrain [9]. It is seen that gentle to moderately sloping areas cover about 705 km^2 (40.69%) of the basin (Table 1). Gentle to moderately steep sloping areas up to 15 which spread in an area of about 1,268.96 km^2 (73.24%) have been given top priority as they are expected to receive and retain more water in the subsurface (Fig. S1).

Table 1. Slope Distribution

Slope Category	Slope Class	Areal extent (km^2)	Percentage
1	Gently sloping	250.54	14.46
2	Moderately sloping	454.46	26.23
3	Moderately steep sloping	563.96	32.55
4	Steep sloping	166.33	9.60
5	Very steep sloping	297.31	17.16

3.3. Lithology

Nature of the rocks is also the one of the significant factors which affects infiltration in addition to the degree of slope and vegetation cover. As the rocks are sedimentary nature there is a wide scope for infiltration in the area. A major part of the basin of about 99.27% (1,719.97 km^2) is covered by sandstones, siltstones & shales. Siltstones, shales and clayey sands have been given top priority due to their high water retention capacity and less permeable [10]. (Table S2 and Fig. S2).

3.4. Flow Accumulation

Flow accumulation is the most important factor as it represents the areas of flow. High flow, medium flow, low flow and non-flow areas can be depicted on flow accumulation raster. Non flow areas are topographically high without any channel development whereas the high flow areas are the channels of actual flow like well-developed streams. The water storage capacity of streams depends up on the channel dimensions like depth, width and gradient. Siltation may reduce the storage capacity as well as the carrying capacity. In fact, the storage capacity of a channel varies with its morphology which is dependent upon the topography of the adjoining areas.

The maximum flow accumulation of the Tlawng River was estimated to be 205,431 m^3 in its lower reaches where the channel width and depth are 53 m and 36 m, respectively, with a gentle gradient. Similarly, the maximum flow accumulation in its upper stream section at an altitude of 546 m above MSL is about 2,139 m^3 where the channel width and depth are 12 m and 21 m, respectively, with moderate to steep gradient. There may be several areas along the streams which have high flow accumulation depending upon the channel dimensions and inflow. It is about 10,000 m^3 on an average in its middle reaches as the channel gradient is gentle to moderate and steep at some sections for a total length of 45 km as seen along the main River channel. The areas with high flow accumulation between 50,000 m^3 and 205,431 m^3 have been given top priority considering the channel dimensions and slope of the neighbouring areas (Fig. S3 and Table S5).

3.5. Drainage Density

Drainage density is one of the significant factors which depict the areas of the density of channel network in unit area. It is the ratio of stream length of all orders in a basin to the area of the basin [11].

The River has very good network of streams though 1st and 2nd order streams flow at higher degree of slope between 15° and 30° and above which occupy higher elevations ranging from 398 m to 750 m in the basin. In the Tlawng River basin the drainage density ranges between 7.77 to 10.38 km/km^2 (Fig. S4). The high and very high density areas range from 9.36 to 9.88 km/km^2 and 9.89 to 10.38 km / km^2 respectively, which occupy an area of about 150.38 km^2 as seen in the central parts of the basin have been given top priority (Table S3). The medium drainage density class which spread in an area of about 661.37 km^2 (38.18%) in the northern, central and southern parts have been given medium priority. Similarly, low and very low classes of drainage density seen extensively in an area of 920.66 km^2 have been given least priority though it occupies large area taking all other factors into consideration. Though, lithology is more or less uniform there is a wide variation in drainage density due to the other factors like slope and also the ongoing tectonic activity. In fact, slope has strong control over drainage network due to the highly rugged nature of the terrain.

3.6. Lineament Density

Lineaments are usually straight or sometimes curvi-linear features of the earth surface representing fractures, joints or faults in the bedrock [12]. Lineaments are comparatively longer than faults and fractures [13].

These are the tectonic features which play a major role in water discharge and also recharge of ground water as they act as conduits. Faults and fractures in the study area are oriented in definite directions like N-S, NE-SW and E-W which indicate the nature of ongoing tectonic activity. A majority of the streams in the basin are controlled by the active faults and fractures.

The lineament density in this basin ranges from 0.163 to 0.491 km/km^2 (Table S4 and Fig. S5). The areas with medium to high lineament density (0.164-0.491) occur in an area of about 873.75 km^2 (50.43) particularly in the middle parts of the basin have been given top priority as they enhance the water recharge capacity of reservoirs. Among the total 98 lineaments identified in the study area, 42% fall under low density and 33% in medium density areas. Though, majority of the lineaments fall under low to medium classes, its length is comparatively lesser than the lineaments present in high density class.

3.7. Land Use/Land Cover

Land use and land cover are the two important physical factors which show the human interaction with the surrounding environment and the dynamics of vegetation. Land cover plays a vital role in developmental planning of any region and at the same

Table 2. Land Use/ Land Cover Statistics of Tlawng River Basin

Land use/ Land cover class	Areal extent (km²)	Percentage
Built-up land		
Village/Town/City	25.89	1.49
Agricultural land		
Wet rice cultivation	1.89	0.11
Agriculture Plantation	4.69	0.27
Forest		
Dense	214.48	12.38
Medium dense	228.61	13.19
Less dense	299.53	17.29
Forest Plantation	7.48	0.43
Bamboo Forest	589.58	34.03
Wasteland		
Land with scrub	22.98	1.33
Barren rocky areas	11.49	0.66
Water bodies		
River	9.7	0.56
Shifting cultivation		
Current	92.18	5.32
Abandoned	224.1	12.93
Total	1732.6	100.00

time it has both positive and negative impacts on all natural processes. The land use and land cover map of the watershed shows several distinct units which have a great influence in the dam site selection (Table 2 and Fig. S6). About 77.32% (1,339.68 km²) of the basin is covered by forest with varied intensities. Built-up land which includes settlements and roads occupy an area of 25.89 km². Wet rice cultivation is practiced in small extent only along the low lying River banks particularly in the downstream areas

of Tlawng River. Shifting cultivation occupies an area of 316.28 km² of which about 92.18 km² (5.32%) is under current cultivation. The abandoned shifting cultivation which spreads in an area of about 224.10 km² over the steep slopes is prone to severe soil erosion causing heavy siltation in the downstream areas and also along the valley sides. Barren rocky areas are seen in the steep sloping areas and also along the steep River banks at places. Agricultural lands, water bodies, shifting cultivation and wasteland feature such as land with or without scrub have been given top priority.

4. Results and Discussion

The thematic data on slope, flow accumulation, lithology, drainage density and lineament density have been selected for integration with the predefined theme weight as shown in Table 3 and Fig. 3 to identify feasible sites for water storage. The criteria used for the selection of the sites are gentle to moderately steep sloping areas adjacent to 3rd and 4th order streams composed of siltstone, shale and clayey sand with high flow accumulation ranging between 50,000 - 2,05,431 m³ in the vicinity of settlements. The thematic data has been integrated with the help of spatial analyst tools as per the criteria defined. The top priority has been given to slope and flow accumulation as they are the decisive factors of water storage in Mizoram due to ruggedness of the terrain. The orientation of faults and fractures have been analysed thoroughly while proposing dam sites as their orientation sometimes may damage the entire structure due to strong ongoing tectonic activity. It is also possible that landslide prone areas also might damage the structure as the terrain is fragile with steep slopes. A total of 32 ideal sites have been identified in and around the 3rd and 4th order streams in the vicinity of Aizawl city considering all the topographic factors (Fig. S7, Fig. 4, Table 4). The selected sites range their elevation from 398 to 988 m above mean sea level. It is seen in Mizoram that the rate of erosion and siltation in reservoirs and River channels is high as the topography is immature
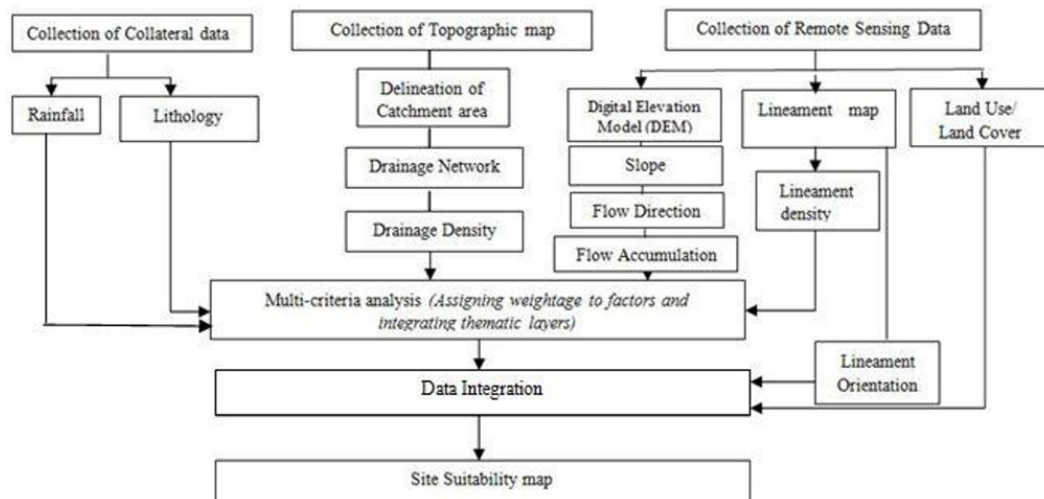

Fig. 3. Work flow.

Table 3. Ranking of Factors

Theme / Physical Factor	Sub-Class	Category	Rank	Theme Weight (%)
Rainfall (mm)	> 3,000	Very Good	1	
	2,500 − 3,000	Very Good	1	
	2,000 − 2,500	Good	2	10
	< 2,000	Moderate	2	
Slope (%)	0 − 5	Very Good	1	
	5 − 10	Good	2	
	10 − 15	Moderate	3	
	15 − 30	Poor	4	25
	> 30	Very Poor	5	
Flow Accumulation (m^3)	50,000 − 205,431	Very Good	1	
	Up to 50,000	Moderate	3	20
	0	Very Poor	5	
Lithology	Fine-grained sandstone and shale	Moderate	3	
	Siltstone-shale	Good	2	
	Clayey sand	Very Good	1	10
	Gravel, sand & silt	Very Poor	5	
Drainage Density (km/km^2)	Very Low (7.77 − 8.29)	Very Poor	5	
	Low (8.30 − 8.82)	Poor	4	
	Medium (8.83 − 9.35)	Moderate	3	15
	High (9.36 − 9.88)	Good	2	
	Very High (9.86 − 10.38)	Very Good	1	
Lineament Density (km/km^2)	Low (0.00 − 0.163)	Moderate	3	
	Medium (0.164 − 0.327)	Good	2	10
	High (0.328 − 0.491)	Very Good	1	
Land Use/ Land cover	Built-up land	Poor	4	
	Agricultural land	Very Good	1	
	Forest	Poor	4	
	Wasteland (Land with scrub)	Very Good	1	
	Wasteland (Barren rocky area)	Poor	4	10
	Water bodies (River)	Very Good	1	
	Shifting cultivation (Current)	Very Good	1	
	Shifting cultivation (Abandoned)	Very Good	1	

with high relief [9]. It has been established that runoff is less in circular basins than elongated basins [14]. In fact, siltation is controlled by basin characteristics such as topography, shape, degree of slope, velocity of flow and drainage pattern. It has been observed that the drainage pattern is mostly dendrite but trellis and parallel types also occur at several places as the streams are controlled by the structures developed by the ongoing tectonic activity.

The Tlawng River basin is highly elongated in addition to the physical factors like high relief with steep slopes and sedimentary rocks which resulted in high rate of siltation of about 18,210 ha.m/100 km^2/year [9]. All the identified sites are prone to erosion than sedimentation as they occupy topographically higher elevations. However, it is also possible that siltation is high at higher elevations due to ongoing shifting cultivation as in Teirei River basin which resulted in severe soil loss of about 80 ton ha^{-1}ya^{-1} [15]. It has been observed in Tuirini watershed that the terrain which ranges from 15° to 45° is prone to more erosion [16]. The high relief and steep sloping areas have been subjected to high rate of erosion in Tut River basin [17]. Similar physical conditions exist in the Tlawng River basin also which might lead to high rate of erosion at higher elevations and sedimentation in low lying areas. Therefore, the studies provide useful input in constructing dams to minimize siltation.

Table 4. Location of Proposed Water Harvesting Structures

Location	Longitude	Latitude	Elevation (m)
1	92o 42' 09"	23o 46' 27"	496
2	92o 42' 53"	23o 46' 22"	592
3	92o 43' 47"	23o 45' 57"	789
4	92o 42' 57"	23o 45' 45"	538
5	92o 42' 23"	23o 46' 23"	447
6	92o 42' 23"	23o 45' 53"	398
7	92o 40' 40"	23o 45' 12"	789
8	92o 41' 40"	23o 45' 29"	618
9	92o 42' 28"	23o 45' 27"	648
10	92o 42' 06"	23o 45' 02"	526
11	92o 42' 42"	23o 45' 0"	687
12	92o 40' 38"	23o 44' 36"	941
13	92o 41' 26"	23o 44' 45"	943
14	92o 42' 02"	23o 44' 35"	875
15	92o 42' 05"	23o 44' 23"	937
16	92o 42' 25"	23o 44' 04"	979
17	92o 41' 32"	23o 44' 15"	962
18	92o 40' 45"	23o 44' 04"	813
19	92o 41' 03"	23o 43' 29"	775
20	92o 41' 56"	23o 43' 28"	790
21	92o 42' 46"	23o 43' 38"	913
22	92o 42' 39"	23o 42' 57"	988
23	92o 41' 42"	23o 43' 02"	918
24	92o 40' 51"	23o 42' 54"	459
25	92o 41' 39"	23o 42' 30"	641
26	92o 42' 43"	23o 42' 28"	841
27	92o 41' 50"	23o 41' 59"	869
28	92o 41' 02"	23o 42' 18"	424
29	92o 41' 05"	23o 41' 43"	616
30	92o 41' 24"	23o 41' 24"	682
31	92o 41' 59"	23o 41' 32"	644
32	92o 42' 37"	23o 41' 54"	875

Fig. 4. Site suitability map of water harvesting structures within 4 km radius of Aizawl city.

the source of drinking water mainly during the lean period. In other districts of Mizoram, wherever the major towns are located within the reach of Tlawng River basin, similar type of methodology could be adopted.

In Mizoram, small RWH structures are more feasible than large RWH structures considering seismic hazards and rapid sedimentation. The topography of the study area being hilly area composed of a large number of narrow valleys which is suitable for construction of RWH.

References

5. Conclusions

Though the present study identified several potential sites for rain water harvesting (RWH), only 32 highest ranked sites have been recommended in the vicinity of Aizawl city. Interconnection between the identified sites could be traced by using lineament orientation. All the selected sites belong to the areas of 3rd and 4th order streams which is a desirable characteristic for the construction of reservoir because the soil in the upstream areas tends to be unstable particularly, in Mizoram as they are sandy in nature. The proposed sites could serve as a supplement to irrigation and
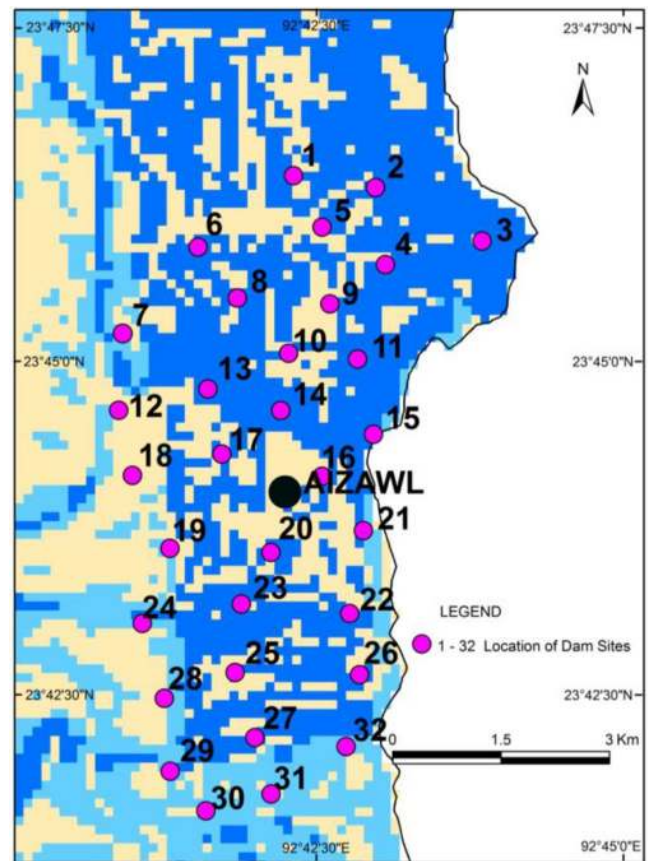
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