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Smart and Sustainable Water Management Using GIS (A Case Study in District Metering Area of Bangladesh)

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Abstract: Dhaka Water Supply and Sewerage Authority, DWASA has planned a smart water management system to decrease the water scarcity in Dhaka city of Bangladesh. The management strategy focuses on a range of actions with a major emphasis on a DMA (District Metering Area) management approach with the principal objective of reducing NRW (Non-Revenue Water) which remained high at around 35% in 2012. For the implementation of this management plan, DWASA has undertaken a project named Dhaka Water Supply Sector Development Project (DWSSDP). The project activity encompasses rehabilitation or replacement of the existing water supply system with the pressurized system for the predicted year of 2030. The aim of the project is to improve the water supply network of Dhaka City through dividing it in District Metering Areas (DMAs). DWASA has predicted that, after completing all the DMAs, this system loss will be reduced to 15%. From our study, it has been observed that after completion of approximately 88 DMAs among 120 DMAs, the gross system loss has been reduced to 23.40%. So, it can be said that DWASA has been successful in implementing smart water management through GIS mapping, online billing system, installing smart water meters and sharing the maps on global platform named GeoDASH. The main aim of our study is to inform about the methodology of the construction of these DMAs and the concept of smart water management using GIS. Therefore, after studying the whole system, this system can also be implemented worldwide to reduce water loss in the distribution system.
Keywords: Smart water management, District Metering Area (DMA), Non-Revenue Water (NRW), GeoDASH.

1. Introduction

The city of Dhaka is supplied with nearly 2.3 billion liters of water every day to its population of about 15 million people. Approximately 78% of the water is supplied from groundwater sources and the remaining 22% comes from surface water sources.

The groundwater is being extracted and as a result the groundwater table is falling at an alarming rate of 2-3 meters every year. DWASA's (Dhaka Water Supply and Sewerage Authority) existing water services heavily rely on groundwater as approximately 78% of the water produced comes from aquifers. However, further reductions are needed to stop the continuous decline of the water table. Over the years, the number of deep tube-wells (DTWs) has increased to nearly 774 across the city. Furthermore, due to disturbances in the aquifer and clogging of DTWs due to over extraction, the yields of DTWs are decreasing and result in short operational lives of about two to three years. As a result, about 40 to 60 DTWs are replaced each year. In addition, synchronization of DTW operations is a significant management challenge. On average, at least 15 to 20 DTWs are out of service on a daily basis due to mechanical and electrical failure.

The management of water sources and water supply for the city of Dhaka is still a major problem even though several large and expensive water supply projects funded by different donors (ADB, World Bank etc.) including the Government of Bangladesh were commissioned. DWASA which is responsible for the construction, operation and maintenance of the water supply systems in the city, is continuously preserving to develop a water management strategy which focuses on a range of actions with a major emphasis on a DMA (District Metering Area) management approach with the principal objective of reducing NRW (Non-Revenue Water) which has remained persistently high at around 35% in 2012. During the last few years, DWASA has taken several initiatives including the DMA management approach to reduce the NRW. These initiatives appear to have paid off and available data indicate that the NRW for the first quarter of 2016 decreased by around 26%. But the sustainability of such significantly lowered values remains uncertain.

2. Literature review

Dhaka Water Supply and Sewerage Authority (DWASA) is a service oriented, autonomous and commercial organization in the public domain, entrusted with the responsibility of providing water supply, sewerage disposal (wastewater), and storm water drainage services to the urban dwellers of the fast-growing metropolitan Dhaka, the capital of Bangladesh.

To ensure safe drinking water supply to the inhabitants of Dhaka city, DWASA had operated approximately 700 Deep Tube Wells in Dhaka in the year 2011 that extract on average 1.950.000 m^3/d [7] from the groundwater reservoirs, mostly from the second and third aquifers. In addition, approximately 1.536 private wells were registered and operated by other agencies, industries or private entities. These private wells extract water mostly from the first aquifer. In total, the average daily groundwater extraction rate was estimated at 3.100.000 m^3/d [7]. The Institute of Water Modelling (IWM) had studied the geo-hydrological situation in and around Dhaka, supported by monitoring data and numerical computer analyses conducted in ModFlow. Based on their analyses, IWM concludes:

- Due to over-extraction of groundwater, the groundwater table in Dhaka is declining at some 3.5 m/year (refer to figure 2below). It is uncertain for how much longer the existing groundwater source can sustain the current extraction rates;
- Extraction from the first aquifer (50-118 m below ground surface level) should be reduced by at least 20% to restore the natural lateral recharge of this aquifer.

DWASA used to extract groundwater from the second and third aquifers. In each DTW, DWASA observed a drawdown of approximately 50 m due to the extraction (static water level = 40 m below ground surface level; dynamic water level = 90 m below ground surface level). The submersible pumps that were installed in the DTWs were generally not designed to pump the required flow over this head, resulting in (i) reduced yield, (ii) low pressure and (iii) high energy consumption per m^3. However, to meet customers´ demand, DWASA had to operate its DTWs constantly, almost 24/7. This promoted rapid (mechanical) clogging of filters and hence the productivity of the DTWs was further diminished. The average life time of DTWs in Dhaka was short, only 3-5 years for DTWs up to 200 m and 2-3 years for DTWs up to 400 m, which was also caused by some inadequate design and construction practices [7].

Due to on-going urbanization and projected population growth and increased water demand, DWASA will continue to rely on groundwater resources in the future. Hence, declining groundwater tables and inefficient operation of DTWs is a key constraint for DWASA in supplying sufficient water to its increasing number of customers. To overcome this problem, DAWASA has planned to switch to surface water for their major water supply source with an emphasis on DMA to reduce non-revenue water – known as smart water management.
The objective of this study is to analyze this smart water management strategy in DMA (District Metering Area) of Dhaka WASA using GIS and its sustainability of reducing NRW (Non-Revenue Water).

3. Methodology of Smart Water Management

The various steps followed for smart water management and DMA creation are described below [7].

3.1 Base Map Preparation

This is done by the digitization of the satellite image. The use of this satellite imagery (Quickbird and Google Earth) allows further verification of the network, particularly by correlation with the road network and building development. Basic development trends have also been established using Google Earth historic data. After the verification, different elements are drawn on that image using GIS by ***EDITOR*** tool.

3.2 Data Collection and Verification

A substantial amount of data had been collected from the zonal offices of DWASA and other sources on the pipe network and this data was collated into a GIS model covering the whole of Dhaka City. This work was performed by IWM under direct contract to DWASA up to 2006. The project has now augmented this information with data covering the intervening period till the present day.
Progressively the water network model has grown in complexity and the need to link with the GIS database has necessitated the purchase of a new computer network modeling program. After evaluation of the different programs on the market, the ease of transferring existing data into the new program and the programs capacities, the recommendation was made to and approved by the Project Director for the purchase of a fully licensed copy of Water GEMS.

3.3 DMA Outline Design

In order therefore to properly manage the system it has to be subdivided into district metered areas (DMAs). During selection of the DMA boundaries the following criteria are considered:

- Number of service connection between 1,000 to 2,000
- Hydraulic separation of the DMA
- At least one or more PTW (Production Tube-Well) within the DMA
- DMA – DMA interconnection points to be able to measure flows in both directions and to have pressure activated valves

As long as the adjoining DMA has not been brought under a 24 hours pressure regime, the control valves will remain closed to prevent loss of pressure in the newly rehabilitated DMA.At present a total of 120 DMAs have been identified and this number will be updated when water demand, availability etc. are calculated and special provisions for external supply are identified.

3.4 Final Design

In this stage of design, the previously prepared database was checked by ***Door to Door Survey*** in field level manually. Connectivity of the networks was also verified and draft output for the pilot DMAs was submitted to DWASA for further verification by zonal offices. Based on the results, this process will be continued for all DMAs, and with continued strong commitment from DWASA a timely delivery of verified network plans will be achieved.

After checking, the existing design was changed for meeting up the demand calculated for 2030 and rehabilitation, new construction etc. were also done to meet up the demand. Pipelines from 100mm to 300mm are included in the model, with the 450mm transmission mains represented as unlimited reservoir connections. Pipes below 100mm are not included in the models.

3.5 Construction and Rehabilitation

Trenchless technology used for new pipe laying and revision in all the DMAs. The contractor, having taken note of the local conditions, will be asked to prepare typical construction details taking his equipment and the local constraints into account. It will also be a necessity for all connections to be replaced and fitted with a domestic or commercially sized meter. The meters are supplied by DWASA.

3.6 Pre-commissioning and Commissioning

After completion or extension of the pipe laying works, the entire system must be tested on structural stability and leak proof. The completion Certificate for the Works can only be issued after successful finalization of the pressure testing. After pressure testing, the pipeline shall be washed out and disinfected. A stock disinfecting solution shall be prepared by mixing for not less than five (5) minutes, in a clean container, bleaching powder (30% available chlorine) and potable water in proportion of 1 part powder to 10 parts by weight. After mixing, the solution shall stand for a future five (5) minutes after which the clear supernatant liquid shall be decanted into clean container. The solution then is diluted to 50 ppm free chlorine with potable water.

Finally, water loss in the pipes can be identified from inflow, consumption and outflow. The tolerable limit of loss is up to **15%.**

3.7 Operation and Maintenance

The pipelines require only little maintenance but all the lines must frequently be checked for leakages or corrosion.

For operation purpose, major control parameters are–

- ✓ Pump Operation
- ✓ PSV (Pressure Sustaining Valve) Operation at Bulk Meter Chamber
- ✓ Bulk Meter and Valve Efficiency
- ✓ Domestic Meter and HC (House Connection) Characteristics
- ✓ Illegal or non-metered Connections
- ✓ Water Balance: Online bills converted to consumption – production gained from water sources of DWASA
- ✓ Online bills conversion done from water rates of residential and commercial categories :

  e.g. 1000 litre = 10 BDT (Residential)
  and 1000litre = 18 BDT (Commercial)
- ✓ Non-Revenue Water (NRW) related to loss–calculated by :

  Production – Consumption = NRW

4. Result and Discussion of The Study

4.1 Smart Water Management (SWM)

Smart drinking water management is a future-oriented water management strategy by integrating ICT-based water management technologies. So, it can be said as managing the entire process of the water cycle scientifically and systematically. SWM can maximize limited water resources, reduce leakage and incidents through information collected from smart devices. Also water and energy savings can be promoted. Smart water network will provide the right opportunity to save money and water.

4.1.1 SCADA (Supervisory Control and Data Acquisition)

In case of DMA operation, this smart management is mainly done by SCADA (Supervisory Control and Data Acquisition). This can also be done with the help of GIS and other ICT devices.

Goals of SCADA: The major goals of SCADA are –

- Establishment of **five DTW-clusters** with centralized control, allowing DWASA to rationalize/reduce pump operators;
- Demonstration of a **Control Centre for 24/7 monitoring of flows** and pressure in five DMAs;
- **Integrate** DTW clusters and Control Centre;
- **Link data to GIS/MIS** departments;
- Provide **training** for DWASA staff in utilization of SCADA technology;
- Explore further **up-scaling**;

Through using SCADA the authority can supervise the different parameters "Table 1" in a completely digital way sitting in one place "Fig. 1" and "Fig. 2".

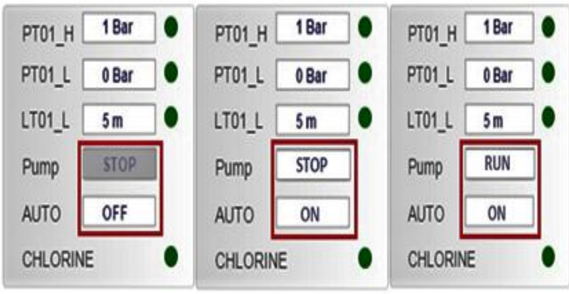


Figure 1. Start and Stop of a Pump Digitally in SCADA System

4.1.2 Smart Metering

For smart water management, another initiative is to install smart meters in all the house connections. The older meters have been incorporated with a chip, which eventually make them smart by giving the reading instantly through computers. Besides this, new smart meters have been installed for completely new connections. The system is known as AMR (Automated Meter Reading) "Fig. 3" and "Fig. 4".

From AMR, the benefits are as follow –

- **Big Data Analysis**
  - Mass analysis
  - Assist decision-making
  - Guide user behavior
- **Cost Efficient**
- **Water Quality Test**
  - Real-time water quality data
  - Ensure secure water
- **User Friendly**
- **District Metering Area (DMA)**
  - Timely control of water distribution system
  - Maximized profitability
- **Pump Station Monitoring**
  - Intelligent scheduling
  - Real-time device operation monitoring
- **Pipeline Monitoring**
  - Leakage locating
  - Non-revenue water (NRW) reduction

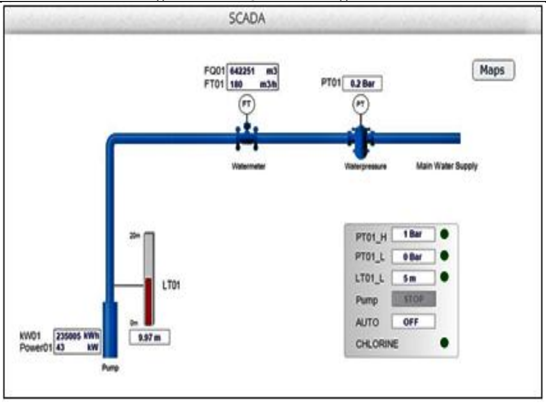


Figure 2. Monitoring of Deep Tube Well (DTW) in SCADA System

Table 1: Parameters for SCADA Supervision

Parameters	**Result / Output**
Water Flow	Current flow (m^3/hr)
Water level in the wells	Water level above pump (m)
Chlorine on location (Disinfection)	Chlorine tank is full or empty
Water Pressure	Pump pressure to pipeline (Bar)
Power Usage	Current power usage (kW)
Alarming	Well low level / Chlorine empty / High or low level pressure

4.1.3 Online Billing System

After implementation of this online billing system, consumers can pay the bills in time without any hassle. The bills can be paid through DWASA website and consumers can also check their dues status from the website. Moreover, the management authority can monitor the payments of the consumers very precisely, as all the information of each and every house connection is incorporated in the DMA map drawn by GIS.


Figure 3. Installation of Smart Water Meter

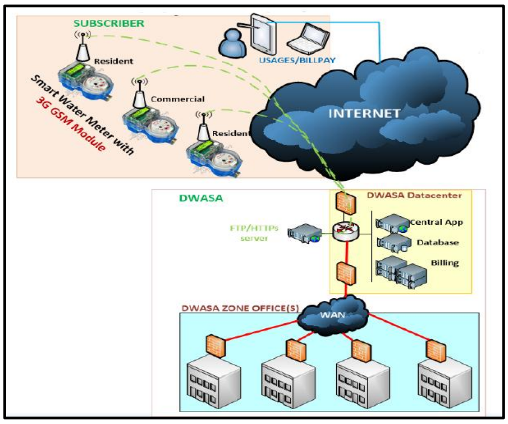


Figure 4. Smart Water Metering System

4.1.4 Role of GIS in Smart Water Management

The database for smart water management through SCADA, smart metering, online billing system etc. has been located and monitored using GIS software. Each DMA has been incorporated in the GIS with all the supporting information. In our study, a map of DMA 501 (Banani) is prepared in GIS "Fig. 5". This map includes –

- ✓ DMA Boundary
- ✓ Buildings, Roads, Footpaths
- ✓ Water Supply Pipe Networks
- ✓ Location of Deep Tube-wells
- ✓ Location of Pumps, Meters, Valves etc.

So, from this map, all the networking elements of water supply and management can be monitored sitting in one place. Information about each and every house connection, meters of those respective houses and also water supply pipes to those connections can be seen from this GIS map at their exact location. So, problem identification and solving have become instant without going to the field.

Moreover, mobile GIS have made the monitoring and data updating process easy and more convenient.

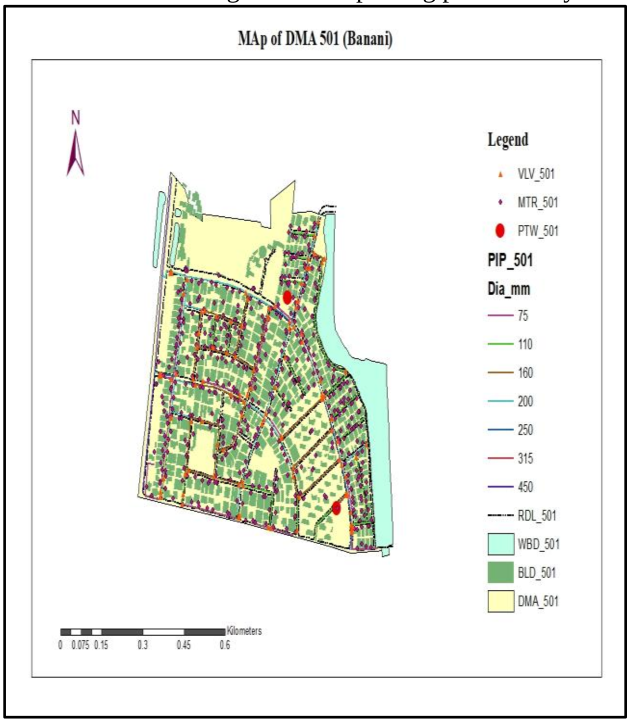


Figure 5. Map of DMA 501 (Banani)

Mobile GIS: Mobile GIS refers to an integrated software or hardware framework for the access of geospatial data and services through mobile devices via wire line and wireless networks. Devices used for mobile GIS are – Notebooks, PDA, Tablet PC, Pocket PC etc.

Mobile GIS should be used for the following reasons–

- ➢ Field works: data collection and validation process, coupled with GPS and wireless communications.
- ➢ Real time update or change
- ➢ GPS integration

4.1.5 Data Sharing Platform (GeoDASH)

GeoDASH is an open source of geospatial data management and visualization platform. The maps can be shared with friends on facebook, twitter, google and email to maximize data sharing. It is also a mapping platform to create custom and stylish maps "Fig. 6".

The web link of GeoDASH is https://geodash.gov.bd/#featured-layers-section.

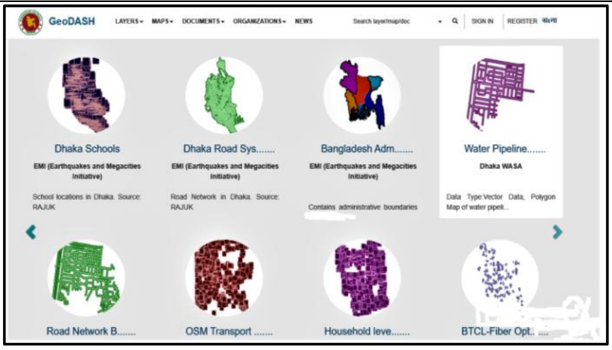


Figure 6. Maps Shared in GeoDASH

4.2 Reduction of Non-Revenue Water (NRW)

Non-Revenue Water (NRW) is the water that has been produced and lost before it reaches the consumer. NRW is actually the difference between the volume of water put into a water distribution system and the volume that is billed to customers.

So, ***Water Production – Water Consumption = NRW***

NRW comprises three components –

1. Real losses (through leaks, sometimes also referred to as physical losses)
2. Apparent losses (through theft or metering inaccuracies)
3. Unbilled authorized consumption

Dhaka WASA has reduced this NRW and managed the water supply system in the following ways [4].

4.2.1 Water Balance Calculation

Dhaka WASA has tried to reduce this NRW through water balance calculation. After the balance has been calculated, the surplus water has been transferred to the area which has a deficit in water balance. For calculation of this water balance, readings have been taken from the meters in the main supply lines [2].

An example of the water balance calculation is given below:

Total Water Production = ∑ Water Consumed + Water Export (if any) + Losses (if any)

Using this formula, the surplus or deficit water can be calculated [6] for DMA 501 (our study area).

4.2.2Export or Import in DMA

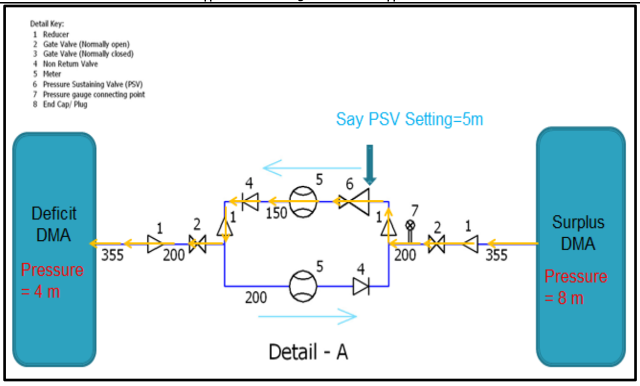
After calculation of the water balance, the surplus water has been transferred to the water deficit area in the following manner “Fig. 7”.

Through all these monitoring and management processes, Dhaka WASA has been successful in reducing their water losses ([1] and [3]). Their target is to reduce the water losses up to 15% after the completion of all the DMAs. From the DWASA annual reports, this reduction to a certain extent has been observed “Table 2”.

Table 2: Gross Water Losses in Past Years in Water Distribution System

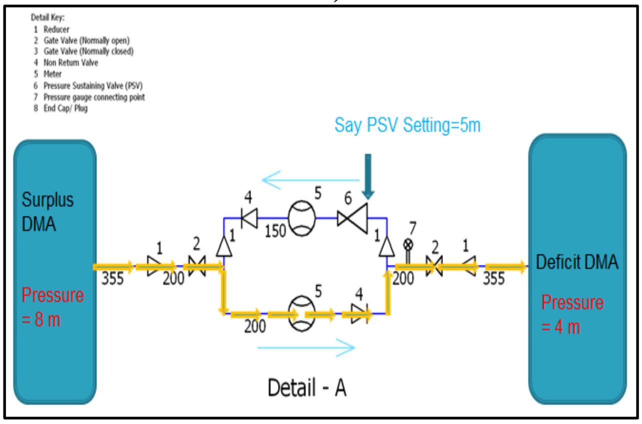
Fiscal Year	Loss (%)
2009 – 10	34
2010 – 11	32.62
2011 – 12	28.80
2012 – 13	26.66
2013 – 14	26.32
2014 – 15	25.43
2015 – 16	23.40

From this table, it can be observed that after the first implementation of DMA concept in 2012, the system losses have reduced to a great extent [5]. So, it can be predicted that there is every possibility of meeting the target of DWASA for reducing NRW after the completion of all the DMAs.



a) Import of Water from Surplus DMA

b)



c) Export of Water to Deficit DMA

Figure 7. Export or Import of NRW in DMAs

4.2.3 Monitoring of Bulk Meters by DMA Map

In case of our study area (DMA 501), the bulk water meters locations are shown in the map "Fig. 8". Through these bulk meters, the export or import of NRW has been operated.

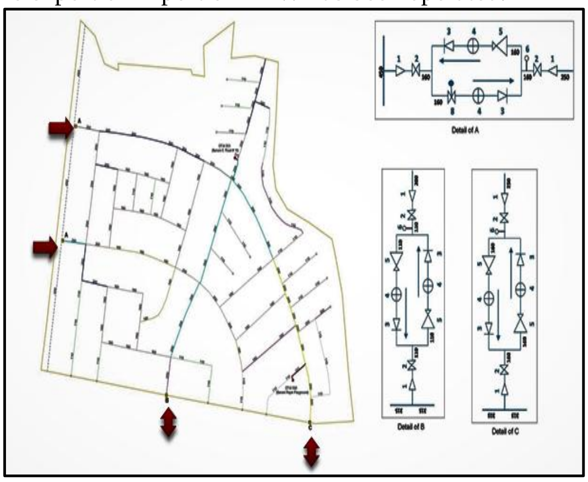


Figure 8. Bulk Meter in DMA 501

5. Conclusion

The Dhaka, a densely populated city of Bangladesh, has been facing acute drinking water problem for days. Supply from groundwater and polluted peripheral river sources have become limited. Besides, more groundwater withdrawal than recharge has caused lowering of groundwater table and decrease in deep tube-well discharge. In spite of all these problems, the various system losses due to the conventional water supply and management system result in scarcity of water in different areas of Dhaka city. So, to minimize these system

losses Dhaka WASA has decided to introduce smart water management system based on DMA concept. The main aim of this system is to reduce NRW (Non-Revenue Water).
Based on the observations on our study area (DMA 501 - Banani), the following conclusions can be made:

- ✓ Proper management of water supply has been implemented through smart water metering, online billing system and monitoring through DMA maps prepared in GIS.
- ✓ Data sharing has been made easier through GeoDASH.
- ✓ Gross system losses have been reduced up to 23.40% by the reduction of Non-Revenue Water (NRW).
- ✓ The introduction of proper monitoring and management in the water supply system has eventually been reduced ground water level depletion and water scarcity in Dhaka city.
- ✓ At times of sudden natural disaster (e.g. earthquake, flood etc.), quick recovery has become possible through locating the damage in the DMA maps in GIS.
- ✓ Moreover, this smart management system can be implemented around the globe as this smart system is completely digitalized and software based. All these softwares are also easily available anywhere in the world.

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