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GIS APPLICATION IN WATER RESOURCES MASTER PLANNING

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ABSTRACT

Due to water scarcity, it is important to organize and regulate water resources utilization to satisfy the conflicting water demands and needs. This paper aims to describe a comprehensive methodology for managing the water sector of a defined urbanized region, using the robust capabilities of a Geographic Information System (GIS). The proposed methodology is based on finding alternatives to cover the gap between recent supplies and future demands. Nablus which is a main governorate located in the north of West Bank, Palestine, was selected as case study because this area is classified as arid to semi-arid area. In fact, GIS integrates hardware, software, and data for capturing, managing, analyzing, and displaying all forms of geographic information. The resulted plan of Nablus represents an example of the proposed methodology implementation and a valid framework for the elaboration of a water master plan.

1 INTRODUCTION

Decision on developing and allocating water resources must be based on their availability, quality, type and rate of use. In fact, this is because of the limitation of those resources accompanied with the increasing demand on water due to world's population increase. Moreover, a water source must usually be allocated to numerous competing uses. When supplies are limited, conflicts among users may arise (Gleick, 1993). Thus, it is important to organize and regulate the utilization of the water resources to satisfy the conflicting water demands and needs.

Water Management is the activity of planning, developing, distributing and managing the optimum use of water resources (Mississippi Water Resources Association, 2013). Water Management planning has regard to all the competing demands for water and seeks to allocate water on an equitable basis to satisfy all uses and demands. Successful management of any resources requires accurate knowledge of the resource available, the uses to which it may be put, the competing demands for the resource, measures and processes to evaluate the significance and worth of competing demands and mechanisms to translate policy decisions into actions on the ground.

Within the context of the essential concern to have clean and sustained water, this paper aims to present a complete methodology for managing the water sector of a defined urbanized region. This main objective will be done utilizing the robust capabilities of a Geographic Information System (GIS), and Nablus, which is a main Governorate located in the northern part of West Bank in Palestine, will be targeted as a case study in order to approach this issue. The paper starts by presenting the planning methodology in the form of steps. Then, it describes in details the capabilities of GIS that can be utilized according to the specialty of the targeted area, in addition to the potential sources of data needed. Finally, sample implementation of the proposed methodology for Nablus Governorate is presented.

2 METHODOLOGY FOR A WATER MANAGEMENT MASTER PLAN

The methodology employs the idea of clusters; dividing the targeted region into several main zones containing neighboring zones, which have alike properties such as elevation and current supplying resources. Clustering is a strategy demanded by a given situation characterized by a big size, generalized with comprehensive impact. This method will be considered to carry out the analysis of the existing water conditions such as consumption and water gap. Later on, measures to find available alternatives will take place, and thus reaching our targeted comprehensive strategic plan.

So, the work guideline can be summarized into the following steps:

1. To accurately study the area of interest from the following aspects:
    a. Location and area
    b. Demography, population and rate of increase
    c. Topology
    d. Water bodies
    e. Land use including built areas
    f. Geology and soil classification
    g. Rainfall
    h. Climate
    i. Culture and education

2. To determine the percentages water uses sectors shares, whether if it is:
    a. Domestic
    b. Agricultural
    c. Industrial
    d. Commercial
    e. Recreational

3. To study the existing water conditions regarding:
    a. Current water supplies
    b. Estimating water demands

    c. Calculating water consumptions and uses
    d. Estimating losses
    e. Evaluating current water position

4. To divide the targeted region into several main clusters. This needs:
    a. Setting up clustering criteria
    b. Suggesting alternatives, then deciding the most suitable clusters division

5. To project water future conditions regarding:
    a. Expecting water future demands
    b. Studying water potential supplies
    c. Estimate potential losses
    d. Estimating water gap (if existing)

6. To suggest and accurately study potential alternatives to fill in the gap (if existing)

7. To propose implementable and feasible project packages needed for each clusters in order to fill in the gap (if existing)

These steps are coherently systematic, but also changeable in accordance to the spatiality and the context nature of each region. Variables such as human activities, cultural nature, industry, religion and political complexities should be considered separately when carrying out any similar planning process.

3 APPLYING GIS

A geographic information system (GIS) integrates hardware, software, and data for capturing, managing, analyzing, and displaying all forms of geographically referenced information. GIS allows us to view, understand, question, interpret, and visualize data in many ways that reveal relationships, patterns, and trends in the form of maps, globes, reports, and charts (Grise, *et al*., 2000-2001).

As the definition explains, GIS is a very powerful tool that allows performing many processes, which are vitally important regarding our scoop of work in this project. We will use ArcMap to conduct the following tasks:

- Data management
- Data analysis
- Decision making
- Data manipulation
- Maps production

The following is the illustration of how we will conduct each of these 5 tasks in our projects.

3.1 Data Management

Such a project encompasses enormous amount of geographical and numerical data. To elaborate, we need the following data:

1. Geographical information about the targeted area including: location, topology, water bodies, land use including built up areas, soil classification, rainfall, and climate.
2. Statistics about the population of each area including the recent numbers and the future projections, i.e. rates of increase.
3. Measurements of the current water consumptions and uses.
4. Information about water conveyance systems.
5. Allocations of current and potential water supplies.

GIS ArcMap manages these data by creating a convenient database including all the related shapefiles and the tables of attributes attached. It might seem as a time consuming and exhausting process, but it vitally organizes and eases the advancement of the work.

3.2 Data Analysis

Several analyses on the available data should be carried on in order to construct further data using the powerful abilities of GIS ArcMap. These analyses include:

1. Hydrological modeling and analysis for the water sources in the area of study to gain information about water inflow, sources replenishment, infiltration, evapotranspiration, and water outflow (Grise, *et al.*, 2000-2001). In order to apply this process, we need to create a set of raster surfaces starting from Digital Elevation Modeling (DEM) reaching our targeted results in a watershed surface.
2. Evaluating water conveyance system using ArcMap water utilities. ArcGIS Water contains a ready-to-use data model that can be configured and customized for use at water utilities. A keystone of this data model is modeling of water networks that capture the behavior of real-world water objects such as valves and lines. We can use this tool to evaluate the existing conveyance system efficiency, and if needed, to expand existing networks or to design new ones.
3. Area calculations for the total area of study, and later, areas of clusters.
4. Performing enormous amount of calculations on the tables of data using the field calculator tools. This tool is very simple and easy to use, but has a crucial importance in work. For example, when classifying water uses into the 5 predefined sectors, and at the same time, keep them related to their spatial dimension. In other words, how much water used in each sector, and where does that happen? As mentioned before, these kinds of information are of crucial importance to the study.
5. Determining the spatial correlation between the area of study and the recent and potential water sources. This can be done using GIS queries and/or GIS buffer tools. That spatial correlation is important to the allocation of these sources.

As already seen, no comprehensive tool other than GIS ArcMap can conduct all of these mentioned analyses. They vary from very complicated analysis such as hydrological analysis to simple ones such as tables’ calculations.

3.3 Decision Making

This tool is mainly used mainly for clustering. At the beginning, certain criteria have to be defined to group related areas in clusters. Here is a suggested criterion:

- Spatial correlation between locations: Locations in one cluster must be spatially correlated, i.e. must have common boundaries.
- Distance and accessibility to water sources: The closer and more accessible the water source the better. This suggests grouping all locations that are closer to a certain source.
- Topography: Topography is crucially important in water conveyance systems consideration. However, the topographic dimension can be considered and dealt with in two different ways. Either to consider grouping out the locations that are similar in topography, or to consider having at least one location containing a high elevation point to locate a reservoir on that point (if necessary).

After setting up our criterion, the powerful tools of GIS ArcMap can be used to apply it in order to make our decision. These tools include: raster surfaces for elevation modeling such as IDW, queries, buffer, etc.

3.4 Data Manipulation

Data are manipulated in two different themes:

1. Cartography: GIS ArcMap provides sets of tools including: editing and drawing tools, clip, merge, intersect, spatial joining, dissolve, etc. to do the following:
    - Apply our decision made grouping locations in clusters.
    - Draw new elements that we might create, such as new reservoirs, water networks, etc.
    - Produce new shapefiles with different content if needed.
2. Numerical Data: GIS ArcMap provides sets of tools including: join, relate, field calculator, etc. to do the following:
    - Produce new tables with different content if needed.
    - Conduct desired calculations.
    - Achieve results.

As noted, GIS ArcMap encompasses variety of manipulation tools regarding many different aspects, which help the user to conduct many desired tasks easily.

3.5 Maps Production

GIS ArcMap is a well-known tool for maps production. It helps the user to integrate data with the main elements of a map in a comprehensive, presentable, and at the same time, aesthetic context that makes the map readable and understandable by any user regardless her/his background. Main elements of a map are: the body, title, north arrow, scale bar and legend. This tool will be used to produce several maps as needed.

4 DATA CLOLLECTION

As mentioned earlier, this project encompasses enormous amount of geographical and numerical data. We need data regarding the geography of our area of study, population, water recent conditions and potential sources of supply.

To achieve a high level of confidence in this project, we need officially well acknowledged sources of our initial data. The following table (table 1) summarizes a suggested list of potential sources of data.

Table 1: Suggested List of Potential Sources of Data

Data Type	Potential Source/s
Geography & Water Conditions	National, governmental or private geographic institutions
	Statistical Institutions
	Local universities / Civil Engineering Departments
	Local Municipalities
	Governmental water authorities and national/private water companies
	Agricultural institutions
Population and statistics	Statistical Institutions

It is important to keep in mind that much further sources of data should arise during the advancement of the process.

5 CASE STUDY: NABLUS GOVERNORATE

Nablus Municipality locates in the northern part of West Bank. According to the administrative division of West Bank Governorates, which was conducted by the PA year 1996, Nablus Governorate has an area equals to (605) Km^2 that makes the governorate occupies 10% of the total area of Palestine and 10.7% of the total area of the West Bank (Palestinian Central Bureau of Statistics, 2007).

The governorate contains only one city, Nablus city, in addition to 61 Palestinian communities, administrated by village councils, in addition to three refugee camps.

5.1 Water Status

The water status of the governorate is quantified by the current and future water demand. The data obtained from the Palestinian Water and Wastewater Sector report of year 2009, which are considered as a reference for the current water demand quantities. The demand is classified between the urban, rural piped (served) and rural unserved areas. For the urban and the rural piped area, the demand is estimated based on the data provided from the water service suppliers, while for the rural unserved areas, the demand is estimated to be roughly 35 L/c/day (Palestinian Water Authority, 2009).

The projection of future water demand is estimated considering the following criteria:

- The main objective is to meet, by the end of the plan, the World Health Organisation (WHO) standards for the minimum domestic (not including other uses such as industrial, commercial, etc.) water consumptive use to meet all hygiene needs, which equals 100 L/c/day (Howard , *et al*., 2003).
- The gradual increase of water consumptive use along with life standards improvement. This is necessary due to the fact that Palestine is a developing country which seeks renaissance and development in the near future.
- The urban development, especially in the rural areas.
- The necessity to serve the unserved areas.

Table 2 summarizes the current and the projected future water demands according to the above mentioned criteria.

Table 2: Current and Future Water Demands

Year	Urban Areas Demand (L/c/day)	Rural Piped Areas Demand (L/c/day)	Rural Unserved Areas Demand (L/c/day)
2007	127	98	35
2010	157	94	50
2015	170	155	110
2020	179	164	141
2030	199	185	167

The total demands estimation (current and future) are calculated according to the projection of population obtained from the Annual Statistical Report of the Palestinian Central Bureau of Statistics for year 2007. The report estimates the Palestinian national population growth rate to be 2.3% (Palestinian Central Bureau of Statistics, 2007). The creation and editing tools of the attribute table for the targeted shapefile in GIS ArcMap are used to perform the projection calculations. For instance, equations 1 and 2 are defined in the created fields (column in GIS ArcMap attribute table of a shapefile).

$$\text{Total demand (L/day)} = \text{Population} \times \text{Demand (L/c/day)} \qquad (1)$$

$$P_n = P_o \times (1 + r)^n \qquad (2)$$

Where:
P_n = population after n number of years
P_o = current population
r = growth rate

Hence, GIS ArcMap powerful tools can be used then for database creation and management.

5.2 Clustering

The following criteria for dividing the governorate into clusters were set:

- Topography: each cluster should contain a location with high elevation for new reservoirs allocation. In GIS ArcMap, for this study, this criterion is met using a layer of contour map overlaid by the communities' layer to identify the communities with highest elevations. However, other graphical surfaces, such as DEM, can be used here in case of having the relevant data.
- Geographic continuity: all communities in one cluster should be geographically connected, i.e. having shared boarders.
- Serviceability: merging the unserved localities in the same cluster or clusters.
- Proximity to water resources: resources should be evenly distributed between clusters. This criterion is checked in GIS ArcMap by overlaying all available water resources (wells and springs) layers with communities' layer.

The consideration of these criteria led to divide Nablus Governorate into 5 clusters: 1. 'Asira ash Shamaliya; 2. Nablus; 3. Beit Furik; 4. Burin; and 5. Aqraba (the naming is considered according to the largest community in the cluster). The clusters are shown the map in Figure 1, which is created by the drawing, shapefiles' creation and editing tools in GIS ArcMap.

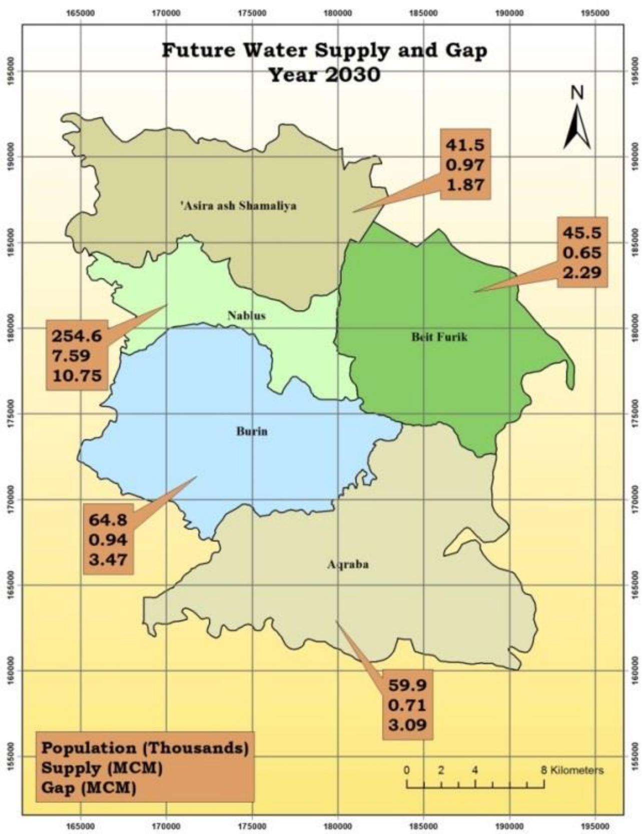

Fig.1: Clusters with Water Gap by 2030

5.3 Alternatives

According to The Palestinian Water and Wastewater Sector report, 2009, the available alternatives are:

- Rehabilitation of existing water networks
- Rainfall harvesting
- New groundwater wells

5.4 Action Plan

The maps in figures 2a, 2b and 2c, which are created by the drawing, shapefiles' creation and editing tools in GIS ArcMap, illustrate the action plan proposed by planners.

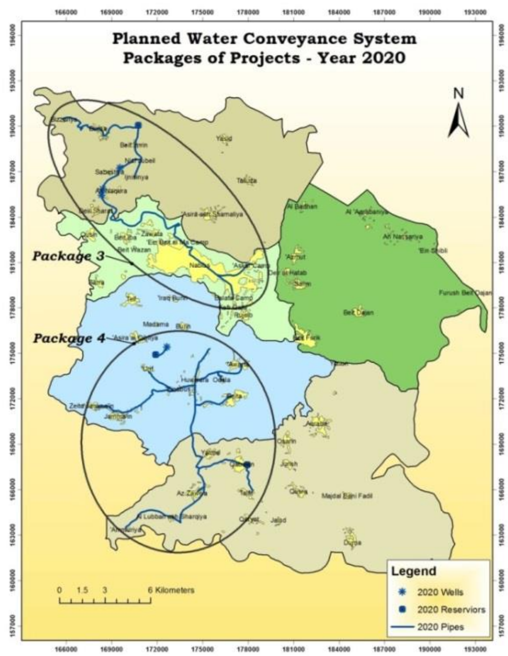

Figure 2a: Action Plan 2015

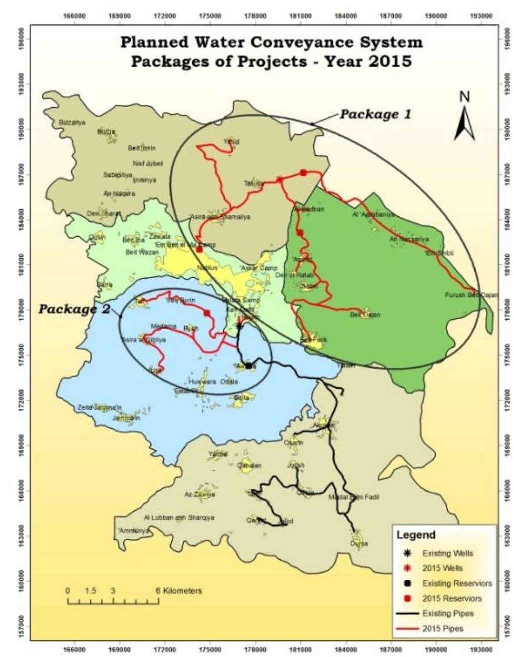

Figure 2b: Action Plan 2020

Figure 2c: Action Plan 2030

The action plan is a set of sequential projects which have clearly defined objectives, description, timeline, funder/s, budget, and different impacts assessments. The discussion of the action plan is beyond the scope of this paper.

6 CONCLUSIONS

Water resources management concerns vary around the globe. The proposed methodology described in this paper approaches master planning for the water resources in the arid to semi-arid regions such as Middle East.

It is clearly noticeable in this paper that GIS ArcMap has very powerful tools for data base creation, editing and management. What makes it unique and very useful is the ability and ease to link these quantitative data to its relevant spatial dimension. Furthermore, all of the previously mentioned tools and capabilities from data analysis, management and manipulation to decision making and maps production are highly contributive to the integrity of the proposed methodological process. These characteristics extensively provide a comprehensive work environment for such type of work.

It is important to keep in mind that this paper provides a methodological framework, not an exact procedure to follow. Moreover, water resources management issues are highly complex and challenging due to the variety and wideness of stakeholders, the complexity of the environmental considerations and the unpredictability of the future scenarios. This necessarily means that the planner/s or researcher/s is/are advised to be considerably flexible in order to manage the variables of each situation.

Following this proposed methodology should lead at the end to having a comprehensive master plan for the water sector of the targeted region. More importantly for decision makers, it collects the suggested alternatives to fill in the gap (if exists) in proposed packages with estimated costs for each cluster. Higher level of management and planning, i.e. the government or municipality, could consider these packages later when they conduct their strategic plans. These processes of continues future projection and planning are vital and of crucial importance for the continuity of human well-being in our communities.

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