GEOGRAPHIC INFORMATION SYSTEM (GIS) BASED HIGHWAY ASSET MANAGEMENT SYSTEM FOR MOTORWAYS: CASE STUDY OF MAJOR PAKISTAN'S MOTORWAYS

F. Ali and Z. Batool

Department of Transportation Engineering and Management,
University of Engineering and Technology, Lahore, Pakistan.
Corresponding author's e-mail:farukalipk@gmail.com

ABSTRACT: Result of pavement condition survey, conducted by NHA in 2005, showed that 43% of existing NHA network has remaining service life (RSL) of0 to1 year. Asset replacement value of National Highway was estimated more than 600 Billion in 2005 by Road Way Asset Management Division. This largest investment is deteriorating at fast pace, main cause being increased axle loading and lack of maintenance.The study was carried out to develop GIS based Highway Asset Management System(GHAMS) for M-1 and M-3Motorways.Digitized database was established to develop Query Basedinterface on ArcGIS. The developed system, GHAMS, produced different outputs like thematic maps, graphs and charts that would assist authorities and decision makers to carry out maintenance/rehabilitation works of NationalMotorways timely and efficiently. Moreover, this query based system would lead to save intense pavement damages and subsequent high maintenance / construction cost.

Keywords: Geographic Information System, Asset management, Highway maintenance, Digitized Database.

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INTRODUCTION

The construction of roads and bridges in Pakistan over the last few years has increased its pace and the trend is likely to grow in the coming years. Management and maintenance of these national assets is one of the major problems being faced by Pakistan now a days. For effective planning, construction, management, and maintenance of transportation assets, it is pre-requisite that these are modeled first by using some information system (Hall, 2004).The solution to this problem lies in the development and implementation of asset management systems such as pavement management system, accident management system, and decision support systems. These systems are augmented with analytical tools capable of performing engineering, accounting and economic analysis help in organizing, prioritizing and strategizing investments for better planning and implementation of objectives (Aboki, 2005).

The American Association of State Highway and Transportation Official's subcommittee on Asset Management defines Transportation Asset Management (TAM) as "Transportation asset management is a strategic and systematic process of operating, maintaining, upgrading, and expanding physical assets effectively through their life cycle. It focuses on business and engineering practices for resource allocation and utilization, with the objective of better decision making based upon quality information and well defined objectives." (FHWA, 2007).

A GHAMS comprises of two types of information; one is spatial data and the other is non-spatial data (attribute data). Spatial data includes the data which is geo-referenced and has a projection and coordinate system associated with it, whereas non-spatial data defines the attributes associated with the spatial data which may point, line or polygon. In case of a highway, non-spatial data includes carriageway width, shoulder width, right of way, number of lanes, history of construction, pavementCondition survey data, traffic volumes and accident studies. These datasets of diversified nature (whether spatial or non-spatial) and having different referencing systems are integrated and manipulated using a well-designed GIS. Once the GIS is developed, the coordinates can be transformed into other projection systems (Jain,*et.al;*2003).

GIS based asset management system defines asset managementthe collection, processing, analysis and maintenance of extensive information about various types of assets such as equipment, facilities and other resources to plan work to be executed to maintain these assets at an operational level in the most cost-effective fashion possible (Lemer, 1998).

In California, the Department of Transportation has recently successfully integrated GIS with the street, signs, trees and other right of way assets inventory and with the existing work order management system. The system collects and manages assets and synchronizes it with the work order management system. The data is inventoried using the Tablet PC loaded with ArcPad and high resolution street maps, street centerlines, address database and digital orthography that enables identification of assets through visual inspection and without GPS. The system helps in efficient and streamlining data collection, management and updating besides effective labour and expense tracking (Jennings, 2009).

Land Transport Authority (LTA) of Singapore also combined geotechnical information pertaining to structural foundations of the transport infrastructure projects. For soil analysis, sit excavation, foundation design and tunnel alignment, GIS technology is used for capturing borehole information and a data of more than 8,000 boreholes was captured by the LTA. The data also helps in location of water table for determination of safe tunneling methods. Particularly for tunnels, soil movement detection enables instruments mapping with GIS is also placed in ground to track any movement in the soil (Freeman, 2009).

Geospatial Airfield Pavement Evaluation and Management System (GAPMS) isdeveloped for the Denver International Airport (DIA) that links airfield pavement management and GIS. Tablet PCs, GPS enables digital cameras and receivers are used by the crews to record distress type, severity and nature while walking on the runway, taxiway, and apron structure. The collected information is also related to the historical data such as the construction contractors, aggregate type used for construction and the prevailing weather conditions at the time of construction for each pavement section (Carlson, 2009).

GIS is used in several fields in Pakistan, but its use for highway assetmanagement has not yet been done effectively. Since 2003, the National Highway Authority (NHA) is using the Highway Development and Management (HDM) Model 4 for prioritization of the assets and development of Annual Maintenance Plan. This model requires pavement condition, road roughness survey, existing traffic characteristics and residual pavement strength as input data and performs the analysis for the complete life cycle of the pavements normally 10 - 40 years andpredicts the pavement deterioration and its impact on road users besides social, economic and environmental impacts. The model performs analysis at threelevels, i.e. strategic level, program level, and project level out of which two types ofanalysis are carried out by NHA i.e. strategic level and program level analysis.

This study has been carried out to develop aGeographic Information System based Highway Asset Management system(GHAMS) for in-use Motorway M-1 and M-3 in Pakistan.GHAMSwill allow integration of datasets (information) such as public safety information, pavement distress informationacross business system within a transportation organization. This system will help different components of the organization to work together on the available data and therefore will help in achieving the maximum potential from the existing system with limited budgets. GIS is also suitable for analysis of information and display in the form of maps. Because of the spatial relationship amongst various transportation facilities and assets, utilization of GIS in transportation is beneficial.

MATERIALS AND METHODS

Following method was used to develop Geographic Information System based Highway Asset Management system (GHAMS), for M-1 and M-3. Initially, satellite Imagery of both the road networks were downloaded using software “Stitch Map” to build one overall map. This software was used to Capture, join and calibrate Google Earth images to one shared map and it waseasily available on internet. The satellite images were downloaded in various pieces at a zoom level of 18 (almost equivalent to 0.6m resolution).After downloading, all the pieces were joined using Global Mapper Software. Afterwards the horizontal alignment of M-1 and M-3 Motorwayswas digitized by using Arc GIS software. The horizontal alignment was divided into segments of 1,000 m each in the Arc Map to create homogeneous sections. Moreover, in order to create a multi-dimensional query based asset management system, data regarding road inventory, road roughness, traffic volume (Data acquired from NHA), accident occurrence and remaining service life of Motorway M1 and M3 was acquired from National Highway Authority. The acquired data was linked with digitized imageries to create a central database for both Motorway M1 and M3. This database acted as a backbone for GHAMS to produce results for different queries.

For the successful implementation of an asset management system, the interaction of processes, people and technology were enormously important (McPherson and Bennett, 2005). Therefore, technologically, there was a need to introduce a GIS based highway asset management for transportation infrastructure of Pakistan that could significantly improve the efficiency of the system. Integration of GIS into the asset management systems in public works departments significantly improved the quality of services delivered to consumers (Ramlal, 2006).

A Database was the most important part of GHAMSas, it was of no use unless it was presented in a logical manner.In order to create a bench mark for the collection of data, the horizontal alignment was divided into segments of 1,000 m each in the Arc MAP. Inline with the study carried out by Mahmood (2009) and considering the key / major highway attributes, a digitized database was developed that included Google Imageries, Road Inventory, Road Roughness, Traffic

Volume, Accident Detail, Year Wise Maintenance Cost and Remaining Service Life.

Pavement Condition and Road Surface Data was collected from National Highway Authorityto assess permanent deformation or fatigue cracking, pavement rutting, patching, edge step, raveling, potholes, and drainage conditions (Table - 1).

Table 1: Pavement Condition Data of Motorway (M1).

Route	Direction	Km.	Surface	Road Width (m)	Left Shoulder		Right Shoulder		Remarks	Roughness	Remaining Service Life (RSL)
					Width (m)	Type	Width (m)	Type		m/km	
M-1	North Bound (NB)	**0**	Asphalt	10.9	3		Not Applicable (N/A)	N/A	overhead bridge	2.66	**4.18**
M-1	NB	**1**	Asphalt	10.9	3		N/A	N/A	Fateh Jang Interchange	2.19	**4.18**
M-1	NB	**2**	Asphalt	10.9	3		N/A	N/A	bridge	2.63	**4.18**
M-1	NB	**3**	Asphalt	10.9	3		N/A	N/A		1.78	**4.41**
M-1	NB	**4**	Asphalt	10.9	3		N/A	N/A		1.84	**4.41**
M-1	NB	**5**	Asphalt	10.9	3		N/A	N/A	Habla Service Area	1.87	**4.41**
M-1	NB	**6**	Asphalt	10.9	3		N/A	N/A	flyover bridge	2.13	**4.16**
M-1	NB	**7**	Asphalt	10.9	3		N/A	N/A		1.96	**4.41**
M-1	NB	**8**	Asphalt	10.9	3		N/A	N/A	canal bridge	2.25	**4.18**
M-1	NB	**9**	Asphalt	10.9	3		N/A	N/A	flyover	1.99	**4.41**

In order to get access demand of M1 and M3, twenty four hours vehicle wise traffic volume data was collectedand entered in the database to conduct different queries. Similarly, yearly maintenance cost of different sections of M1 and M3 wasacquired for the last five years i.e. from 2009 to 2014 for database development. Additionally, data regarding accident occurrence at different sections of M1 and M3 along with Remaining Service Life was acquired from NHA to create multi-dimensional database to generate different queries using single interface.

RESULTS AND DISCUSSIONS

GIS was shown to be a state-of-the-art technology which could efficiently perform the district's data related processes (Zhao and Stevens, 2003). The GIS Based Highway Asset Management System (GHAMS)had several applications that would help to display query results and would give an overview to the stakeholders for taking decisions. The major applications includedThematic-Maps, Graphs, Charts, Attribute Detailed Reports, Labeling, Query based results, Single Click Information Display, Print,Export, Rehabilitation and Maintenance Cost Calculation.

Chainage(Measurement) of Motorway (M1) after every kilometer is shown in Figure-1for south bound and north bound. Likewise, thematic maps could be displayed and printed for any particular section along with its Annual Average Daily Traffic (AADT) information.

Similarly, a digital map of Dhaka Sylhet National Highway (N2) was developed by (Alam, *et. al*; 2008) to facilitate the highway transportation organizations.

One of the goals of asset management was to replace reactive maintenance with planned maintenance with more practices geared toward predictive and condition maintenance reported by (Harlow, 2000) was in line with this concept, highway asset management system which enabled users to run queries regarding different attributes like location of bridges, Sections of M1 and M3 with certain remaining service life, Road Roughness

Detail and Accident Data which would be helpful in future planning.

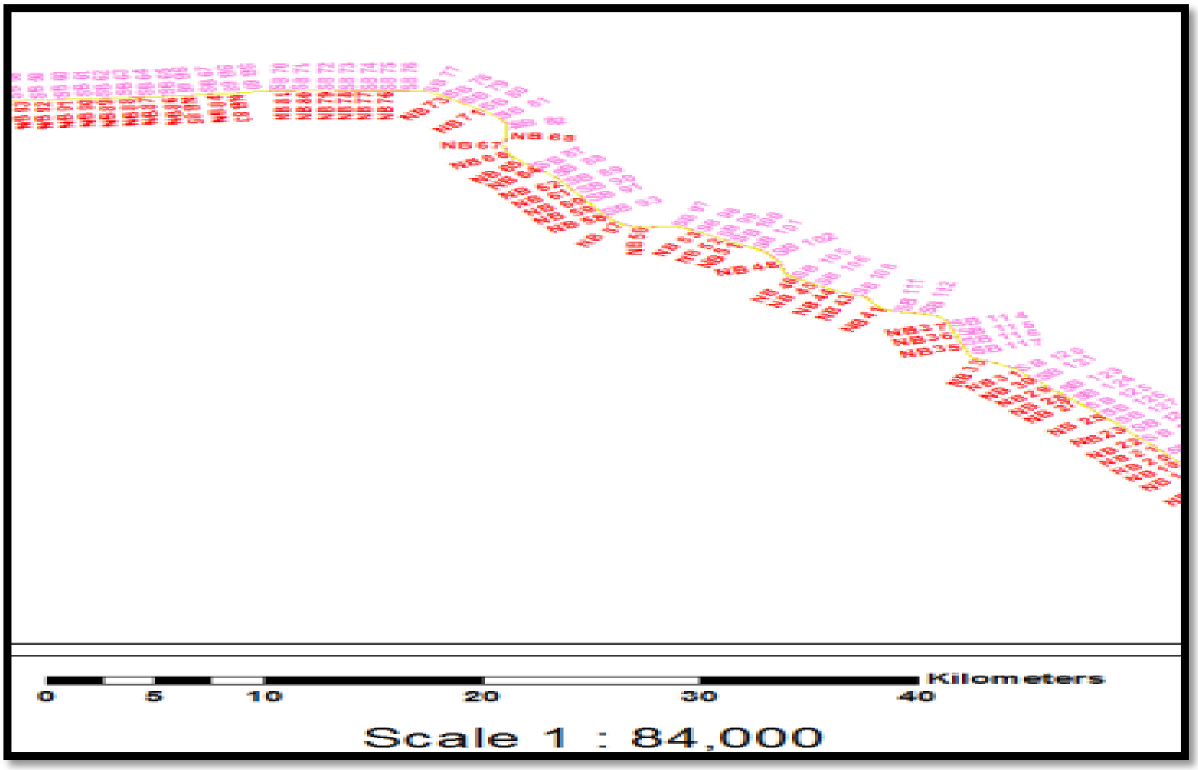

Figure 1: Thematic Map of Motorway (M-1) with Chainage.

Figure 2: Thematic Map of Motorway (M-1) with digitized Image in the Background and Labels on Roadway components

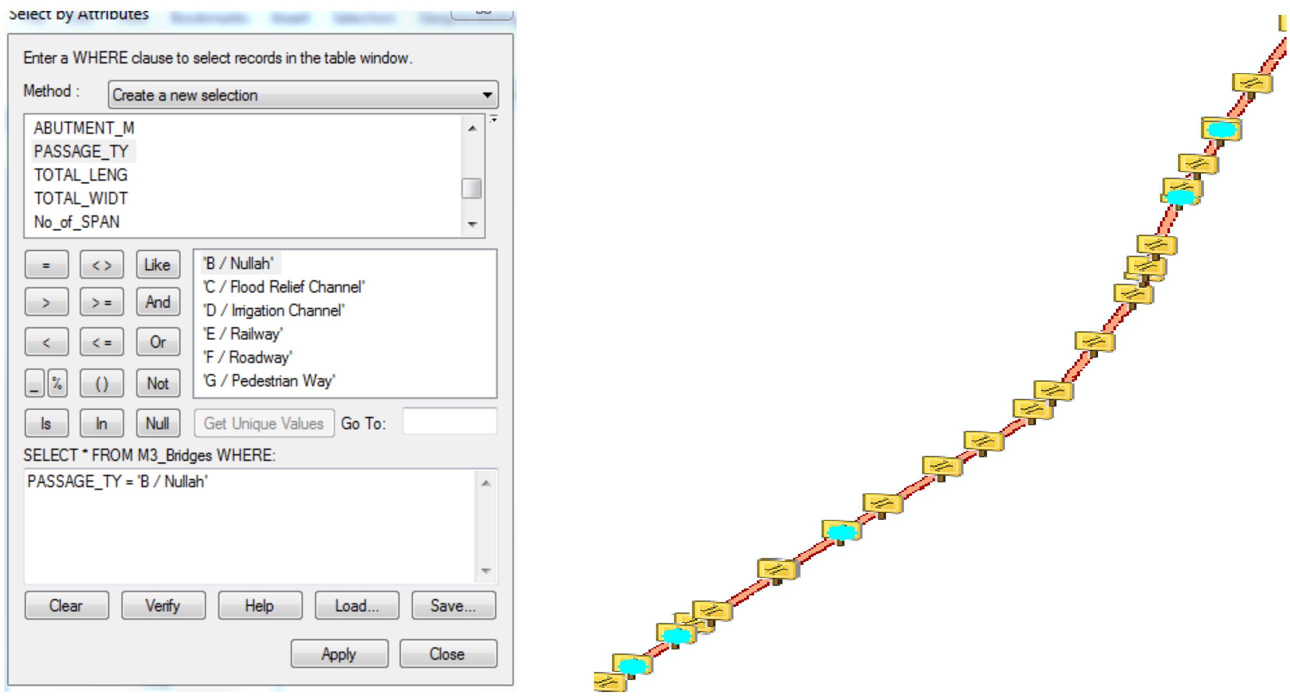

Figure 3: Bridge Located over Nullah only along Motorway M-3

The results of the query raised regarding sections with more than 4.11 years of service life areshown in figure 4. The light blue color showed sections with more than 4.11 of RSL.

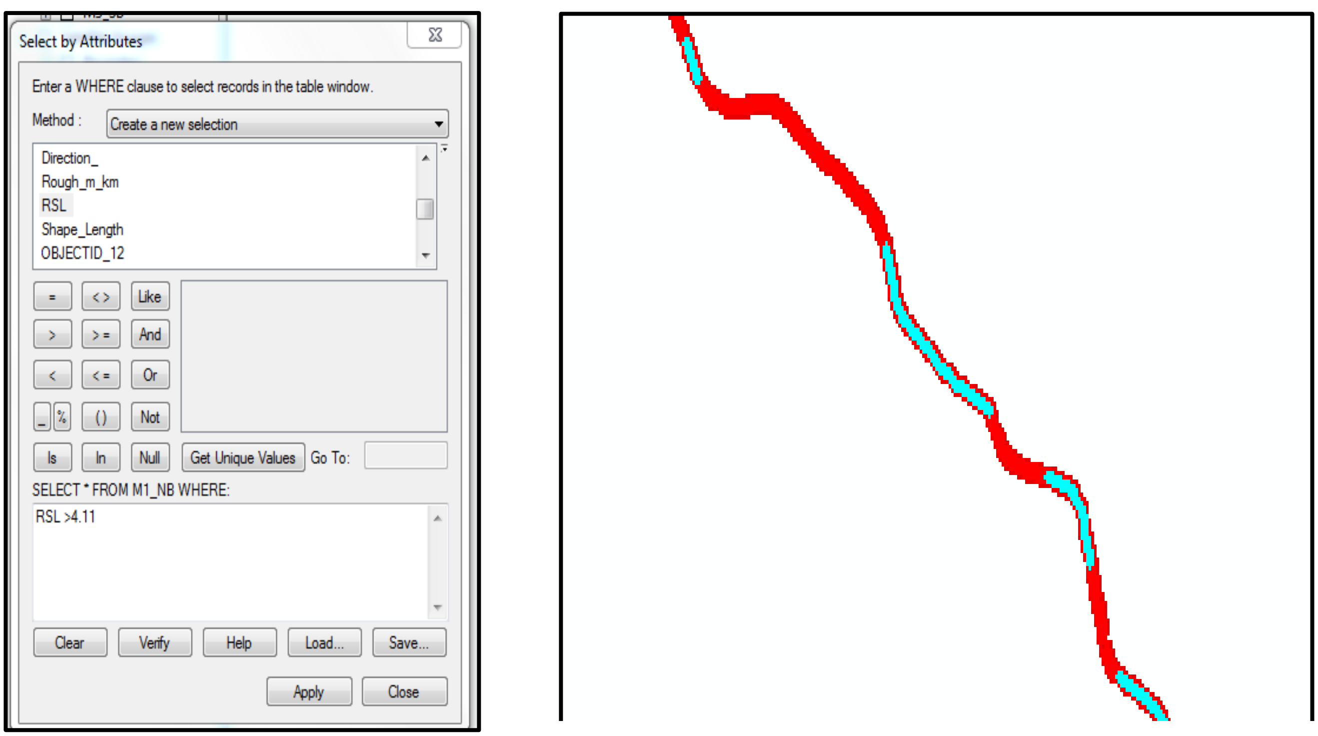

Figure 4: Section of Motorway M-1 with Remaining Service life more than 4.11 years

In a study, Asma and Falih(2012) stated that a comprehensive fully integrated Pavement Maintenance and Management Systems (PMMS), was the key to better reconstruction, restoration and maintenance decision making of pavements. The result of the present research study werein line with the aforementioned statement and query using GHAMS to assess remaining service life of pavements. The results of the sample query are described in figure-5, where blue highlighted sections showed the road roughness greater than 2 i.e. poor surface condition. This information was used to help determine where to best spend capital funds to maximize the value of a utility's assets (Crothers, 2011). Whereas, figure-6 depicts the sections where accidents were reported in the past.Similarly, results were proposed by Evangelidis, *et, al*. (2006)using the design and pilot implementation of an integrated Traffic Accident Information Systems (TAIS).

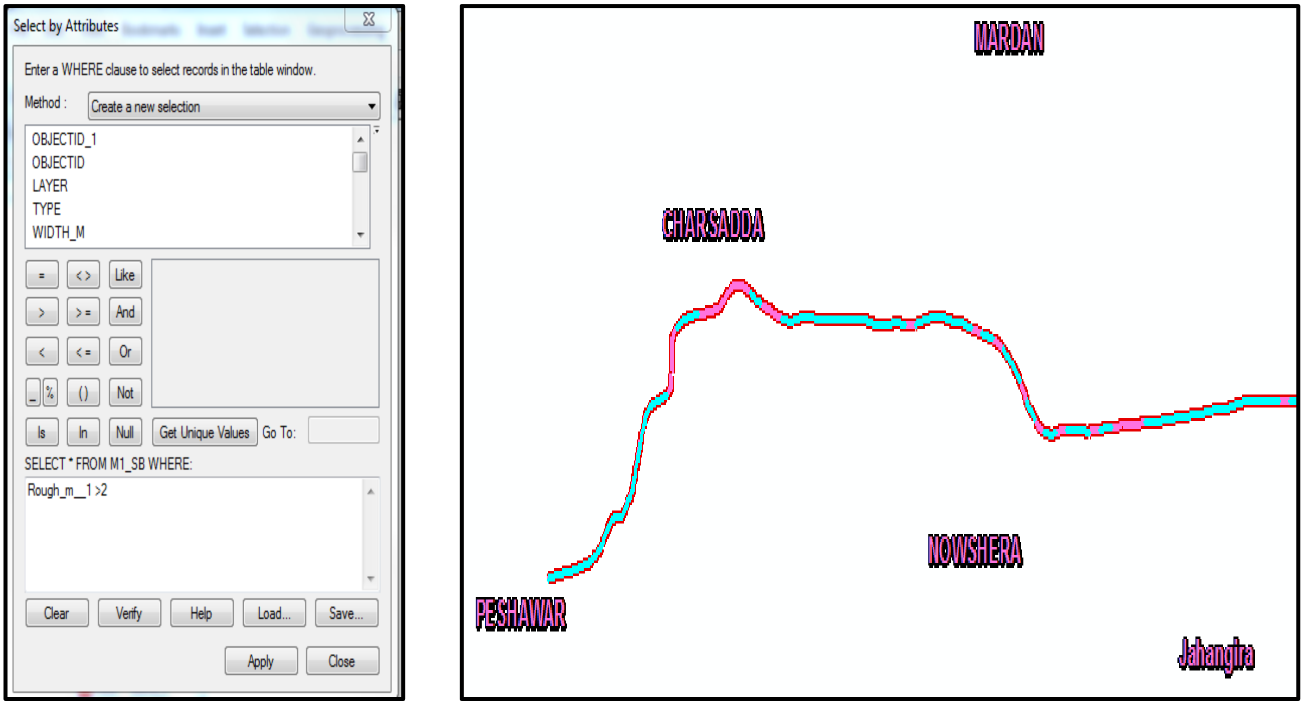

Figure 5: Sections of Motorway M-1 with Road Roughness more than 2

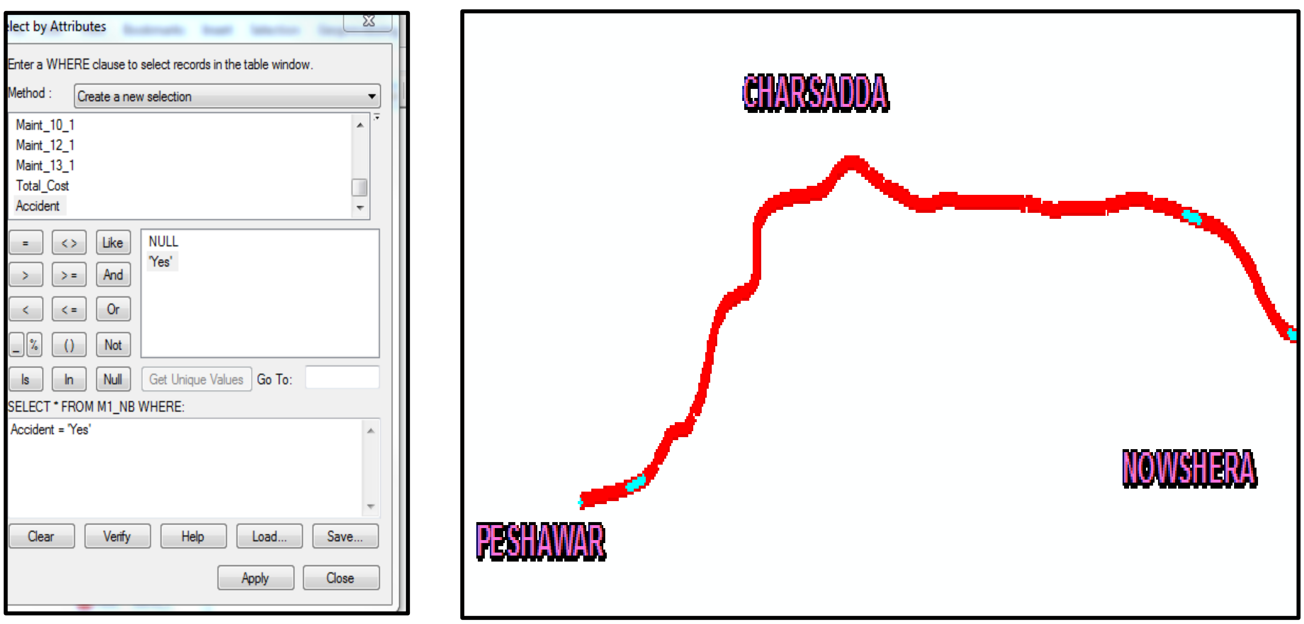

Figure 6: Motorway M-1 Section with Accident Occurrence

Conclusion: The developed GHAMS for M1 and M3 is designed to facilitate the transportation and construction engineers as well as the NHA for effective planning and manage strategic infrastructure investments by generating different queries in this system. It is utmost important for Pakistan, being a developing country with fluctuating economy, that systems like GHAMS may be adopted and extended to all infrastructure management authorities for timely maintenance and subsequent cost- savings,related to redevelopment of road infrastructure. Moreover, more attributes related to Motorway M1 and M3 may be added in the developed database to enhance query options. Other transportation related software be explored and integrated into Arc GIS such as TRANSCAD as Arc GIS is solely not sufficient for this purpose.

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