SPATIO-TEMPORAL ANALYSES TO ESTIMATE SPEED INFORMATION FOR TRANSPORT FORECASTING AND SCENARIO TESTING

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Yunus Serhat BICAKCI
Marmara University

SPATIO-TEMPORAL ANALYSES TO ESTIMATE SPEED INFORMATION FOR TRANSPORT FORECASTING AND SCENARIO TESTING

Yunus Serhat Bicakci[1], Beytullah Sarica[1], Mete Ercan Pakdil[1], Batuhan Yazirli[1], Hande Demirel[2,*]

[1]Istanbul Technical University, Institute of Informatics, Istanbul, Turkey
[2]Istanbul Technical University, Faculty of Civil Engineering, Istanbul, Turkey

ABSTRACT

Road transport, especially congestion, contributes about one-fifth of the European Union (EU)'s total emissions of carbon dioxide (CO2) and is considered as one of the major sources of global greenhouse gas emission. To understand the nature of congestion, speed information is vital, but not yet integrated into transport scenario models. The speed information is currently available via Information and Communication Technology (ICT) Infrastructure, so the possibility of introducing speed data into the transport model should be explored. Hence, the aim of the study was to integrate dynamic speed data from real-time urban navigation road network into a static transportation scenario testing model namely TRANS-TOOLS ("TOOLS for TRansport Forecasting ANd Scenario testing") model. In order to associate and integrate the speed data, a frame-work was designed and spatial interpolation methods being fixed width buffer method and Inverse Distance Weighting (IDW) were tested and compared in a case study area at Istanbul, Turkey. The major contribution of this study was to model the temporal dimension of the speed data via utilizing spatial analyze tools and associate such information with global scenario testing transportation models. The results were promising, where all speed information retrieved from urban navigation maps were associated with the TRANS-TOOLS network and simulated hourly. According to the results of analyzing, the free-speed assumed by the scenario testing transportation model was reduced drastically, being 77% on average, for weekdays. Hence, spatial analyze methods could successfully fill the gap in the transport model and could aid the policy making process.

KEYWORDS:
congestion, carbon emissions, Geographic Information Systems (GIS), spatial interpolation methods

INTRODUCTION

According to the European Commission "Trends in global CO2 emissions 2014 Report", the yearly carbon emission has been estimated as 3.7-4 billion tons, where reduction of emissions are highly ranked at the agenda of policy makers. The traffic congestion plays a big role and affects the amount of carbon emission directly. The delay costs due to road congestion in Europe are over €110 billion annually according to Joint Research Center (JRC) Scientific and Policy Reports (2012) [1]. The current status of traffic congestion related emissions and estimations for future scenarios are ranked as high priorities. For testing transport relevant policy scenarios, transport models are available and widely used. However, most of the transport policy models do not include speed information or information available are free-flow speeds, where in-situ congestion information is not considered. For integrating traffic congestion information, traffic congestion zones should be determined, where several difficulties are apparent. These zones are dynamic, hence changing according to the pick hours in urban areas. Furthermore, the vast amount of real-time data should be stored, modeled and analyzed. The problem is how this big data should be treated to help to reduce and manage different scenarios. Recently, rapid developments in Information and Communication Technology (ICT) Infrastructure reveal the real time speed information publicly, where this information have not been yet associated with the transportation models. Geographic Information Systems (GIS) could effectively facilitate this complex task, due to the spatio-temporal nature of the problem. Several spatial approaches are available to retrieve speed information from real-time dynamic traffic information maps and to associate such information to transport models to generate speed zones for hourly/daily bases. Pfoser at al. have generated spatio-temporal datasets to simulate real-world behavior. [2] For creating a congestion map, Loret et al. analyzed situations of heavy and congested traffic in urban areas by using a statistical approach based on both the identification of specific locations that attract drivers in a multipoint-to-multipoint traffic structure and their classification (attractor's value) as a function of the number of people visiting them by car in different time ranges [3]. Kernel Density Estimation (KDE) function was applied on attractors' distribution density values to estimate and integrate with nodal and critical traffic points and traffic density in a "congestion" map. Anitha Selva Sofia S.D., Nithyaa R., Prince Arulraj G. stated traffic congestion as a condition on road networks occurred by slower speeds, longer trip times, and increased vehicular queuing, where traffic congestion varies from time to time [4] Using SPSS16 (Statistical Package for the Social Sciences), a GIS-based model was used to identify the traffic congestion. Trude Torset studied the speed prediction model for heavy vehicles [5]. It was based on a large quantity of GPS speed reported data and geometry data made available from the National Road Database by the Norwegian Public Roads Administration. The speed prediction model used geometry variables to calculate realistic speed, that could be include into any route guidance system. For analyzing congestion data, especially impact analyses and geostatistics were mature methodologies, that quantitative results were achieved [6], [7].

Within this study, the congestion zones were formed by the speed data segments retrieved from real-time traffic information database for the case study area in the Istanbul Metropolitan Area, Turkey. Such information was recently freely available on-line. The urban road network was associated with TRANS-TOOLS ("TOOLS for TRansport Forecasting ANd Scenario testing") model, which was the major model used for transport policy analysis in EU for aiding policymakers. During this association process conflation methodologies and spatial analyzes were applied. In order to associate the speed data, a frame-work was designed and spatial interpolation methods namely, spatial overlay, buffering and inverse distance weighting (IDW) were tested and compared to estimate speed information. The speed information generated was used to create congestion zones dynamically, where policymakers could benefit from testing their congestion reduction and carbon emission scenarios.

DATA AND METHODOLOGY

Case Study Area. The case study area was the Anatolian side of the Istanbul Metropolitan Area, Turkey. Istanbul is located on two continents (Europe and Asia divided by the Bosporus), surrounded by the Black Sea at north and the Sea of Marmara at south, in the north-west of Turkey. With its 13.854.740 million inhabitants, Istanbul is the most crowded city of Turkey according to the Turkish Statistical Institute. It connects Europe and Asia by the shortest path of roads and railways, where Black Sea region countries are connected to the Mediterranean Sea via Bosporus- a natural strait. Furthermore, the 4th Pan European Corridor ends in Istanbul. Economic activities of the city mainly concentrate on services sector which has 73.1% and industry which has 26.7%. According to the Turkish Statistical Institute, passenger transportation via highways was %72.9 in 1960, where the value was %91.8 in 2010. As a result of investment policies focusing heavily on roads, the industrial facilities and unplanned increase of population along the network were increased like worldwide, while the arable lands and forests were vanishing. According to municipality public transport authority -Istanbul Electricity, Tramway and Tunnel Establishments- (IETT), the public transport trips for 2014 was 2.5 million/day, where cars passing bridges were 53 million per year. The lack of coordination between transport policies, land use policies and environmental policies caused a growth of an expensive and polluting transport system even for Istanbul which has a well-linked multi-modal (maritime, air, rail) transport system. The congestion is one of the major problems within Istanbul. In this study, Kucukyali area locating on the Asian side was chosen to collect speed data from road segments and to compute congestion zones, since this area connects the 4th Pan European Corridor and one of the congested urban areas in the city. (Fig. 1.)

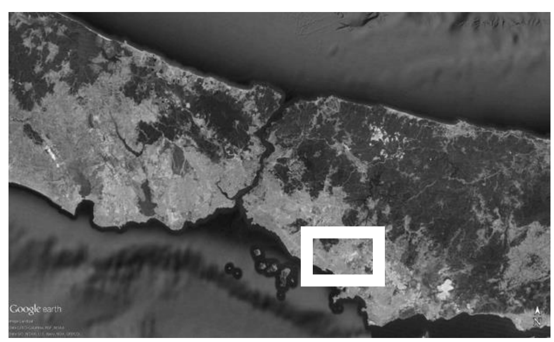

FIGURE 1
Istanbul Metropolitan Area, Turkey

Data. Two road networks were used within this study being real-time urban navigation maps and TRANS-TOOLS. Due to rapid innovations in ICT, most of the urban areas are equipped with real-time urban navigation maps, where dynamic traffic information could be freely retrieved by citizens. For the Istanbul Metropolitan area several sources were available, where for this study Yandex information provider was selected. (https://yandex.com/ company/

technologies/maps/) The service uses the latest satellite images, address databases and GPS tracks. The provided map allows showing traffic conditions and planning routes, creating various information layers and building applications for mobile devices, where information provided could be used to design geo-information services. The speed values were retrieved for weekdays and weekends, where the time slots were 09.30-13.30-17.30 and 22.30. The second road network was the TRANS-TOOLS ("TOOLS for TRansport Forecasting ANd Scenario testing"), where several valuable information for policymakers are embedded to the network and is open source as well. (http://energy.jrc.ec.europa.eu/transtools/TT_model.html) The model has been developed in collaborative projects funded by the European Commission Joint Research Centre's Institute for Prospective Technological Studies (IPTS) and DG TREN. The various Commission services addressing transport issues have agreed to use TRANS-TOOLS as the main model for policy analysis and have appointed IPTS as the model's Reference Centre.

Methodology. The aim of this study was to enhance the road network with dynamic speed data. The TRANS-TOOLS road network is a representation of topological connectivity rather that geometric representation, therefore there is a considerable difference between datasets in detail, generalization, multidimensionality, scale and accuracy. Within this study, the geometrical components of the candidate dataset were not going to be transferred; only relevant data was regarded for transformation. Due to the varying nature and spatial characteristics of data, different methodologies were being applied. Since road databases reveal a different geometric and semantic accuracy from each other, the attempt of a direct integration fails. The problem of merging different data sources representing the same phenomena was well known and named as conflation. “Conflation” combines information from at least two spatial datasets to achieve enrichment in either the spatial or the attribute aspect. [8] Conflation is the process of matching features between data sets created at different times and based on different levels of accuracy and precision. Once features have been matched the goal is often to transfer attribute data from one dataset to the other. Conflation could be horizontal or vertical and it could be vector-vector or vector-raster. Methodologies for solving conflation were available being simple buffer masking, spatial adjustment-involving rubber sheeting-, and combination of these. To achieve the correct matching result, the combination of different methods, such as “Buffer Growing”, Angle-, Length- and shape - Comparison (Spatial Adjustment), could be built. Geometric similarity measurements are often based upon simple information like distance, length, angle or linearity. Within this study simple buffer masking was being applied due to TRANS-TOOLS data nature, to optimize the balance between the run-time and quality of matching. For merging and matching networks representing the same phenomena, buffer growing and iterative closest points or combination of them were the most frequently cited algorithms in the literature.

Two methodologies were compared within this study, being fixed width buffer method and Inverse Distance Weighting (IDW). The fixed buffer method is the most commonly used methodology. It is a buffer that has a uniform, unchanging width all the way around the object. This type of buffer is used with the assumption that the impact zone of the buffered object has an equal impact all the way around itself. The Inverse Distance Weighting (IDW) methodology is an interpolation that estimates cell values by averaging the values of sample data points in the neighborhood of each processing cell. IDW is vastly used for point-based estimations, where several environmental analyses via IDW have been performed for the study area as well [9], [10]. The closer a point is to the center of the cell being estimated, the more influence, or weight, it has in the averaging process. The kriging methodology, which is also powerful for such analyses, was not preferred here, since speed data has limited impact zones and can not be attributed to the whole area. In order to automate the process of calculating and generating several speed maps of congestion for different time intervals the conceptual model was generated. (Fig.2.)

RESULTS AND CONCLUSION

The two distinctive road networks were associated via conflation methodologies. The speed information was retrieved from the real-time traffic information map and associated with the transport model, TRANS-TOOLS, for the study area.

For analyzing the congestion zones, the congestion points were collected by observing daily speed values for weekdays and weekend. As the first method, spatial intersection of fixed width buffers was applied to these points in order to assign speed value that corresponding segment on the TRANS-TOOLS road network. Two kilometer buffer zones were created for representing the conflation of two networks, after some trails of different radius values. [11] Finally, intersecting buffer zones were identified and dynamic speeds were associated. Figure 3 presents the output of this technique.

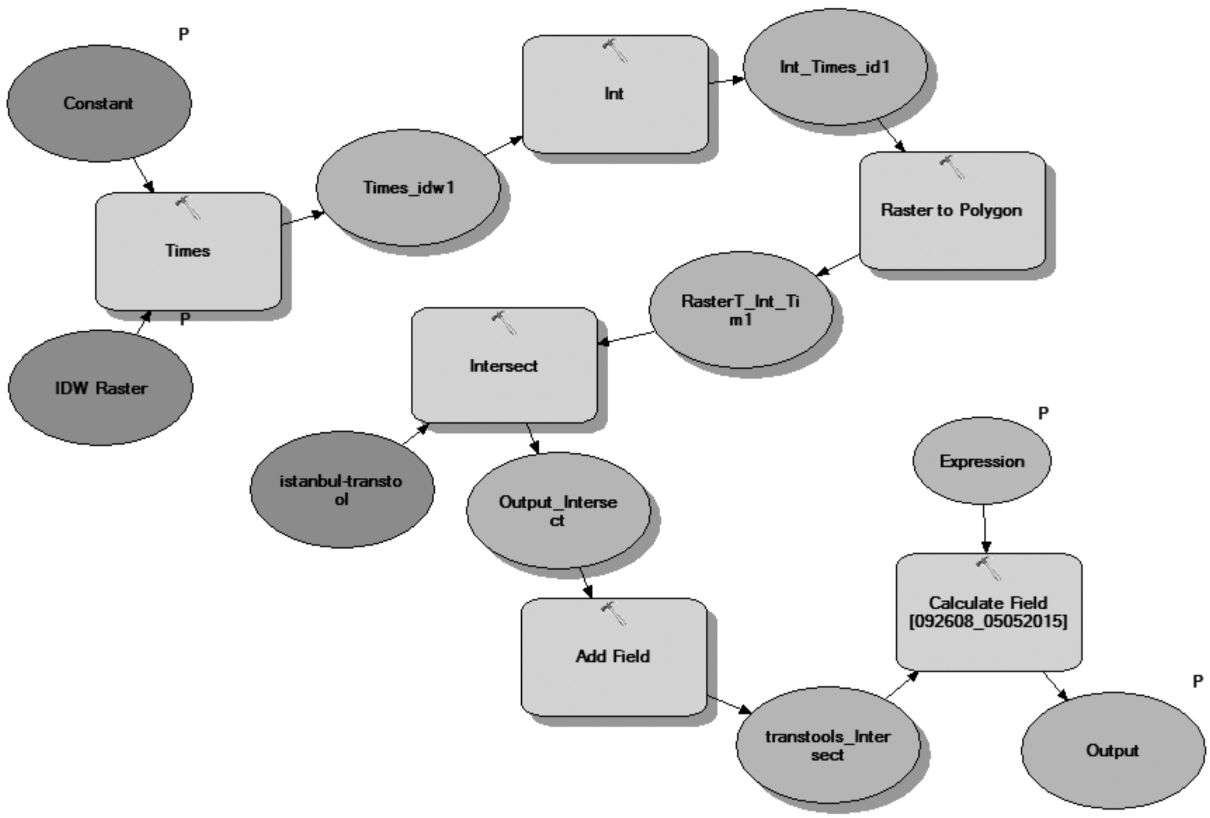

FIGURE 2
The model used to produce of dynamic speed information for different time intervals per day automatically

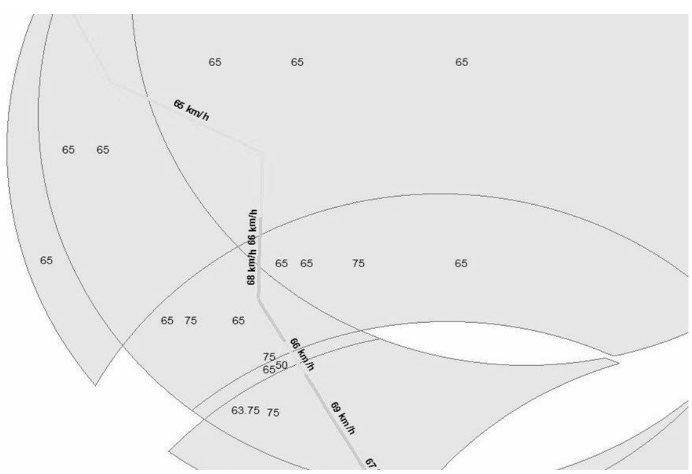

FIGURE 3
Speed zones were intersected with roads utilizing fixed width buffer method.

The second method, IDW, is a type of deterministic method for multivariate interpolation with a known scattered set of points. The assigned values to unknown points were calculated with a weighted mean values available at the known points. Thus, this interpolation technique was used for the given problem in order to assign speed values based on the computed points. The following steps were applied to assign speed values to the TRANS-TOOLS model via IDW analysis:

Step 1: IDW analysis tool was applied to the computed points to produce a raster layer including distributed speed value ranges.

Step 2: Spatial join analysis was applied to assign speed values to zones produced by IDW analysis tool. To apply this analysis, raster layers were converted to the vector layers.

Step 3: Each zone of speed values were assigned to the intersection of corresponding road segment.

Step 4: The speed values of each zone were displayed.

Step 5: Intersect Geo-processing tool was used to split a road into the segments in order to assign each zone's speed value that corresponding segment.

Step 6: A model was created to simulate the traffic data. This model produced six different road segments that have multiplied speed values with different coefficients corresponding to a time interval in one day.

The network representing the 4th Pan European Corridor within the study area was represented as one link within the TRANS-TOOLS model. The free-speed provided by the model was 100km/hr. After associating the dynamic urban road network with TRANS-TOOLS and applying the IDW algorithm, this one link was split into three different segments according to the speed zones. According to the estimations, the average speed of the link was 33 km/hr per day, where the average speed values for each segment in weekdays within 09.30 in the morning and 22.30 at night was illustrated in Figure 4. The output of the IDW analysis, that presents the congestion zones, were illustrated in Figure 5 and Figure 6.

When the IDW model outputs were compared with fixed buffer method, the IDW methodology represented the real situation better. In the "fixed width buffer method", the assigned speed values were considered as uniform data rather than increasing or decreasing trend assumption. But speed values were expected to change according to the distance from the congested zone center of the assigned point in the real world. Hence the "IDW analysis" was applied, where time was the parameter. Since all congestion zones were determined for week and weekend days, simulations of the current status were performed. The snap-shots of the model output were presented in Figure 7. Different line types, as defined at the legend, were representing the congestion level from the most congested to the lowest congested level respectively. Time slider tool was used to visualize and comprehend the congestion level change during the time interval in the TRANS-TOOLS model. The red spots on the TRANS-TOOLS network presents the speed less than 20 km for the determined time lots, where yellow segments showed the speed between 20km and 35 km. Green segments showed the traffic speed was more than 35 km, where no congestion was expected.

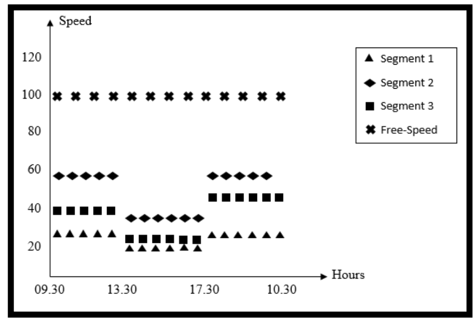

FIGURE 4
Estimated speed for the study area, average for the week days

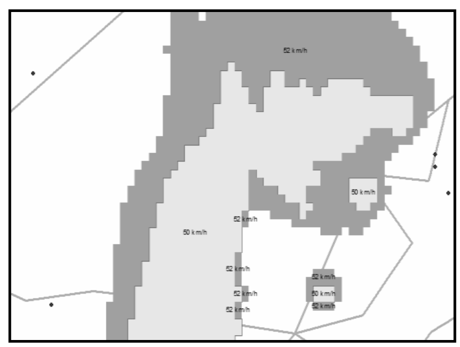

FIGURE 5
The speed values were assigned to each interpolated zone produced by IDW.

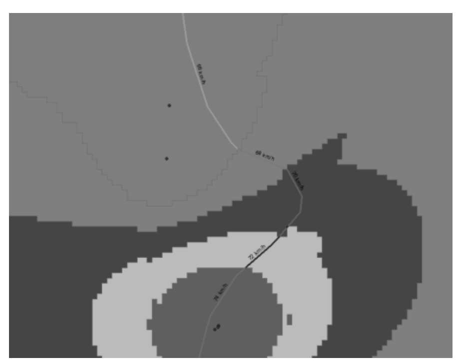

FIGURE 6
The speed values were assigned to the intersected road segments

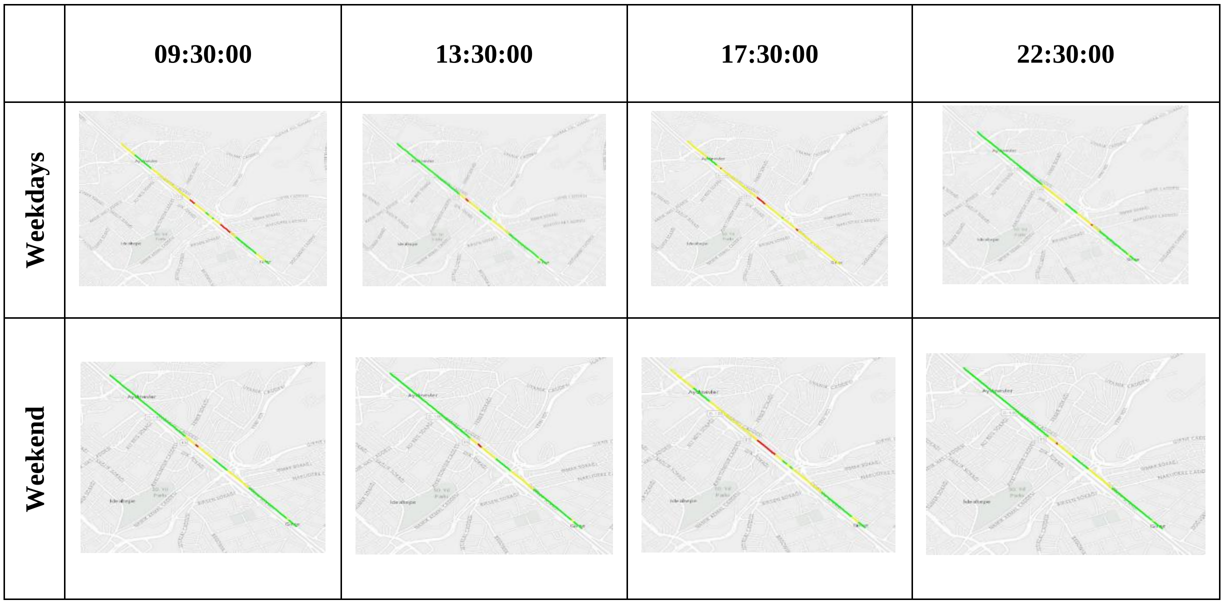

FIGURE 7
Changes of road congestion for the different time period of a day.

This initial study to associate two road networks of having various generalization levels via GIS was effective and presents valuable results. The speed information retrieved from urban real-time navigation road network was associated with static TRANS-TOOLS network that could aid to test many emission reduction scenarios realistically. Two methods were used to assign the speed information from navigation map model to TRANS-TOOLS model. The fixed width buffer method mostly relied on accurate data and any error will generate inaccurate buffer delineation. The IDW interpolation method was more realistic with respect to congestion zones. The proposed methodology within this manuscript could be scaled up to larger urban areas, where the influence of the hierarchy between road types should be explored in detail. The spatial analyze methods proves that the gap in the transport models could be filled via GIS, where such analyses could aid policy making process.

REFERENCES

[1] Christidis, P., Ibanez, Rivas, J. N., (2012) European Commission, Measuring Road Congestion, JRC Technical Notes.

[2] Pfoser, D., Theodoridis, Y., (2000) Generating Semantics-Based Trajectories of Moving Objects, Aalborg University, Computer Technology Institute PO.

[3] Loret, E., Gullotta G., Fea M., Sarti F., (2012) Department of Civil Engineering and Computer Science (DISP), University of Rome, Council of Presidency, Italian Geophysical Association, Earth Observation Science Strategy, Coordination and Planning Office, Directorate of Earth Observation, European Space Agency, Department of Geology, University of Rome (ESA).

[4] Sofia A., S., Nithyaa R., Arulraj P., (2013), Minimizing the Traffic Congestion Using GIS, IJREAT International Journal of Research in Engineering & Advanced Technology, Volume 1, Issue 1, March.

[5] Torset T., (2011), The speed prediction model for heavy vehicles, to be presented at in a season about Traffic Model at ETC.

[6] Sivri, N., Seker, D.Z., Balkis, N., Zan, A. (2012) Analysis of chlorophyll-a distribution on the south-western coast of Istanbul during 2008-2010 using GIS, Fresen. Environ. Bull., 21, 3233,

[7] Gurel, M; Erturk, A; Seker, D.Z; Tanik, A; Ekdal, A; Avsar, C; Ozturk, I., (2011), Estimation of monthly diffuse nutrient loads for a watershed in Turkey, Water and Environment Journal, Volume: 25, Issue: 2 Pages: 219-229.

[8] Yuan S. and Tao C. V., (1999), Development of Conflation Components, proceedings of Geoinformatics'99, International conference on Geoinformatics and Socioinformatics, Ann Arbor, Michigan, USA, June 19-21, pp. 579-591.

[9] Say, A. N. O., Sivri, N., Erturk, A., Seker, D. Z., Li F., (2010) Analysis of phytoplankton distribution at the south-western coast of Istanbul utilizing GIS, Fresen. Environ. Bull., Volume:19, 9B, pp.2116-2122.
[10] Sivri, N., Balci, M., Durmus, T., Seker, D. Z., Balkis, N., (2012) Analysis of enteric bacteria distribution in the gulf of Gemlik (Marmara Sea) by means of GIS, Fresen. Environ. Bull., Volume: 21, 11, pp.3224-3232.
[11] Demirel, H., Sertel, E., Kaya, S., Seker, D.Z., (2008), Exploring impacts on environment: of road transportation a spatial approach, Desalination, Volume: 226, Issue: 1-3, Pages: 279-288.

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CORRESPONDING AUTHOR

Hande Demirel
Istanbul Technical University
Faculty of Civil Engineering
Department of Geomatics Engineering
34469, Maslak/Istanbul- TURKEY

E-mail: demirelha@itu.edu.tr