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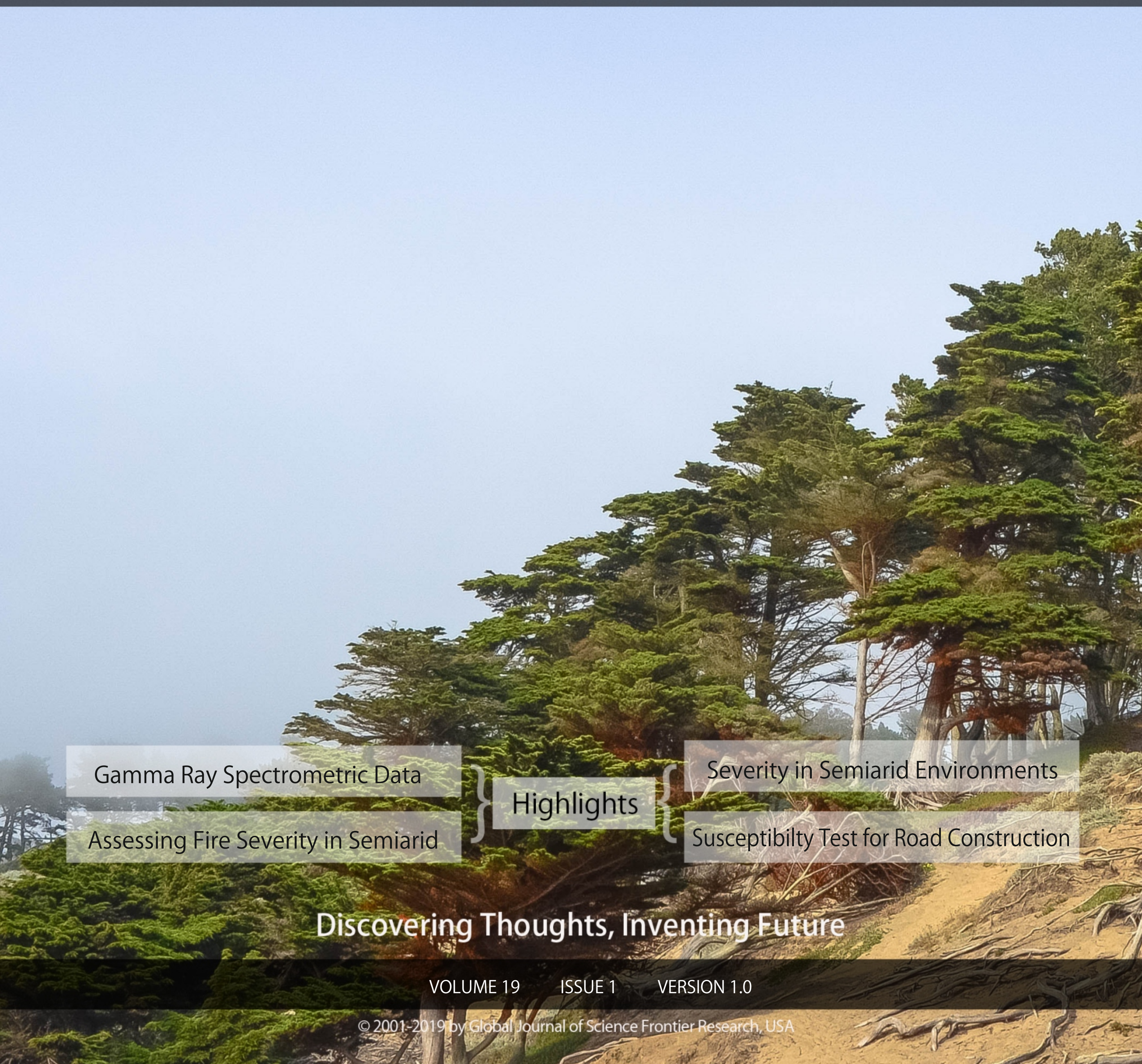

Highlights

- Gamma Ray Spectrometric Data
- Assessing Fire Severity in Semiarid
- Severity in Semiarid Environments
- Susceptibilty Test for Road Construction

Discovering Thoughts, Inventing Future

VOLUME 19 ISSUE 1 VERSION 1.0

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# Smart Sustainable Cities: Using a Fuzzy Inference System to Determine their Global Score

By Oswaldo Redig de Campos Filho, Waléria Guerreiro Lima & Rodrigo Felipe Albuquerque Paiva de Oliveira

*Abstract-* This article assumes the premise that there is no alternative other than sustainable development. The necessary escalation to sustainability will force organizations and public administration to adopt an adequate stand to the sustainable development, mainly when it comes to the promotion of policies that shall guarantee the fulfillment of the triple bottom line (sustainability tripod) for the next generations, also respecting cultural and political issues. This research has collected data from four cities all around the globe using forty-six 'ISO 37.120:2018' core indicators. We have compared, using an adapted fuzzy logic model, the general sustainability score of cities in developing and developed countries. The event of trying to determine a methodology that can be used by any city of any country requires a considerable amount of researching, especially when it comes to choosing which better indicators are fit to the challenge - at the end of the article, we offer a schematic of a smart sustainable city, which we have called "sustainability mandala". Using the same system (with different weighs for each variable,), those answers will help public managers to understand their indexes as a result of positive efforts over the indicators, always on the pursuit of a really sustainable society.

*Keywords: sustainability; ISO 37120; sustainable development; fuzzy logic.*

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SMARTSUSTAINABLECITIESUSINGAFUZZYINFERENCESYSTEMTODETERMINETHEIRGLOBALSCORE

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# Smart Sustainable Cities: Using a Fuzzy Inference System to Determine their Global Score

Oswaldo Redig de Campos Filho [α], Waléria Guerreiro Lima [σ] & Rodrigo Felipe Albuquerque Paiva de Oliveira [ρ]

*Abstract-* This article assumes the premise that there is no alternative other than sustainable development. The necessary escalation to sustainability will force organizations and public administration to adopt an adequate stand to the sustainable development, mainly when it comes to the promotion of policies that shall guarantee the fulfillment of the triple bottom line (sustainability tripod) for the next generations, also respecting cultural and political issues. This research has collected data from four cities all around the globe using forty-six 'ISO 37.120:2018' core indicators. We have compared, using an adapted fuzzy logic model, the general sustainability score of cities in developing and developed countries. The event of trying to determine a methodology that can be used by any city of any country requires a considerable amount of researching, especially when it comes to choosing which better indicators are fit to the challenge - at the end of the article, we offer a schematic of a smart sustainable city, which we have called "sustainability mandala". Using the same system (with different weighs for each variable,), those answers will help public managers to understand their indexes as a result of positive efforts over the indicators, always on the pursuit of a really sustainable society.

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## I. Introduction

According to the United Nations (2005), cities inhabitant number will increase in 2.5 billion people until 2050. By then, UN estimates that more than 68% of the world population will be living in urban areas (UN, The 2018 Revision of the World Urbanization Prospects). This growth in urban population implies significant challenges to natural resources usage, biodiversity, socioeconomic factors, among others (OCDE, 2012), and it also leads us to believe that cities all around the globe will need a significant amount of investments in infrastructure (Ramaswami et al., 2016). According to *European Commission Directorate-General for Research and Innovation* (2015), the term 'infrastructure' can be defined by any means as a whole system that provides water, sanitation, energy, food, shelter, transportation, communication, solid residue and public space management, all of them essential to promote human well-being and economic development. Contemporary cities are seen as a source of big social problems (Bibrie Krogstie, 2017), once they make use of 70% of the world's available resources (being great energy consumers) and, therefore, having an immense contribution to greenhouse gas emissions (GHG) – also because of the density of urban population and the intensity of their economic and social activities (not mentioning the inefficiency of their built areas). All above-mentioned shows the need for discussions about the role of sustainability on urban planning, to find answers to the challenges of the fast- evolving urbanization process - as well as the lack of sustainability of the actual urban forms.

Regarding Bulkeley e Betsill (2005), the best way for cities to restructure would be to adopt long-term approaches that focus on sustainability. Thus, it is necessary to design urban systems that manage their growth and development in a way that mitigate the adverse effects that these cities cause (Antrop, 2004). Urban systems are considered systems that operate and organize life in a built environment, taking into account infrastructure, ecosystem services, human services and, of course, its management process (Bibri e Krogstie, 2017). Still, it is essential to understand that these systems are sensing an increasing pressure due to the enormous challenge sustainability brings, allied to the biggest wave of urbanization in history. The existing built environment is already associated with numerous negative environment, social and economic impacts - including unsustainable energy use and concomitant GHG emissions -, increased air and water pollution, environmental degradation, poor land use, social deprivation, inefficient mobility and accessibility, restricted public safety and health, outdated digital infrastructures, and even the shape of the cities (that affects people, resources, habitat, and climate) (Colldahl, e Kelemen, 2013; Jabareen, 2006).

Although it is not easy to define sustainability, it is necessary to consider it is a concept that leverage the knowledge about how human and natural systems interact, for designing, developing, implementing, evaluating and improving engineering with practical solutions and interventions. This solution shall support the idea of social and ecological systems in equilibrium - as well as nurturing and maintaining links between scientific research and technological innovation -, and public policy and administration processes in relevance to sustainability (Bibri e Krogstie, 2017). Together with

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this approach, urban sustainability denotes the desired state in which society strives to reach a balance between protection, integration, economic development, equity and social justice, all as long-term goals through strategic urban development process (Bibri, 2013). In this way, one can define smart sustainable city defined as a modern environment that uses technologies to improve the quality of life, competitiveness and operational efficiency of urban services, ensuring the availability of resources for present and future generations regarding social, economic and environmental aspects (Kondepudi, 2014).

A city is considered sustainable when it can keep or improve the health of its environmental system, reduce degradation and anthropic impact, reduce social inequality and provide basic living conditions, as well as a healthy and safe environment (and also build political agreements that allow the society to face present and future challenges). Thus, to be considered sustainable, a city does not only have to provide its inhabitant's balanced environmental conditions, but to do so by maintaining low levels of negative externalities over other regions (near or far) and the future. It implies focusing not only on the local scale of sustainability, but also on the regional (made of the interactions with the surrounding areas) and global ones (Mcgranahan e Satterthwaite, 2002; Miller E Small, 2003).

It is important to emphasize that one of the challenges to building sustainable development is to create measurement instruments capable of providing information that makes it possible to evaluate the degree of sustainability of societies, monitor their development trends, and help on the definition of improvement goals (Polaz e Teixeira, 2009). But if sustainability is not easily defined, even more complex is the way to measure it. Such measuring is only possible by 'reading' the environment through previously established indicators (Gagliardi et al., 2007). These indicators allow one to understand the state of the environment in its various aspects, selecting - among all available information - those characteristics that can explain a particular situation, with a descriptive, valuable and predictive approach that can assist decision making (Gagliardi, 2002). Sustainability indicators have also been used as a way to improve the information database about the environment, economy and society, to assist in the elaboration of public policies, to simplify studies and reports, and to ensure comparability between different regions (IBGE, 2008; Milanez e Teixeira, 2003).

To reduce the complexity of sustainability assessment, the International Organization for Standardization (ISO) provides globally agreed standards to ensure the quality, safety, and performance of a wide range of smart cities. One can consider that the adherence to smart city standards offers numerous benefits in deploying and managing smart cities while facilitating real-time monitoring performance (The British Standard Institution, 2014). More recently, sustainability indicators were designed to explore the level of sustainable development in urban communities. Those indicators were proposed by the standard *(ABNT NBR) "ISO 37120:2017 - Sustainable development of communities - Indicators for city services and quality of life*" (ABNT - Associação Brasileira de Normas Técnicas, 2017).

Unfortunately, there are no common units of measure for sustainability indicators, nor are there quantitative criteria for some of their values. Thus, a systemic method based on a reliable scientific methodology, which combines multidimensional components and assesses uncertainties, is necessary. Such a method should be flexible in a way that indicators can be added or removed to obtain a better assessment of the system according to the context (Phillis e Andriantiatsaholiniaina, 2001). For this reason, the use of linguistic values based on a fuzzy logic methodology (MUNDA et al., 1994) seems more appropriate to evaluate sustainability. The following two basic characteristics justify the use of fuzzy logic: (1) it has the ability to deal with complex and polymorphic concepts that are not directly quantifiable and contain ambiguities - moreover, reasoning with such ambiguous concepts may not be clear and obvious, but diffuse; and (2) provides mathematical tools to deal with ambiguous concepts and reasoning, and then provides concrete answers to problems full of subjectivity (since sustainability is, by its means, a subjective concept). What seems unsustainable to an environmentalist may be sustainable for an economist - and the ingredients that mean sustainability may differ for these specialists. There is another important aspect of fuzzy logic: it uses linguistic variables, performing computational analysis with words. If a traditional mathematical approach to sustainability assessment is adopted, such as cost-benefit analysis or algebraic formulas, then certain factors - which are impossible to quantify - would be left out. There are also aspects of sustainability that cannot be quantified and still are very important, like values and opinions. In this case, the logic of fuzzy human thinking successfully performs this evaluation (ZADEH, 1973; ZIMMERMANN, 1991).

In this context, this study adapted a model based on Fuzzy Logic to process the indicators proposed by ISO 37120:2017, aiming to provide a general score that quantifies and qualifies the level of sustainability of cities. This approach to sustainability has the objective to develop a comprehensive decision support framework that allows smart city managers and investors not only to understand the requirements of their cities, but also to identify their strengths and weaknesses and to develop strategies in response to sustainable development requirements.

## II. Methodology

*a) Data Mining*

We started by collecting data from cities at the "World Council on City Data - WCCD Open City Data Portal" (*http://open.dataforcities.org/*), to calculate The General Fuzzy Score of a city. This portal "hosts WCCD Global Cities Registry™ for ISO 37120 and a network of cities committed to improving city services and quality of life with open data" (World Council on City Data - WCCD Open City Data Portal). At WCCD Open City Data Portal, one can find a big number of cities that are, over the time, disclosing their information for a better good. The city data provided by the WCCD is showed through ISO's 37120 Standard indicators, each one of them covering specific areas of sustainable development.

For the purpose of this research, we have chosen (from WCCD Open Data Portal) cities that (1) didn't miss not even one core indicator value and (2) the final calculated Global Score result was or smaller than 30 (poor index) or bigger than 40 (strong index). The four cities that met these criteria were: (a) Tbilisi (GEO), (b) Guadalajara (MEX), (c) Boston (USA) and (d) London (UK).

*b) Explaining the (ABNT NBR) ISO 37120:2017 Standard*

Developed by ISO/TC 268 (Technical Committee 268, 2012), the "standardization in the field of Sustainable Cities and Communities will include the development of requirements, frameworks, guidance and supporting techniques and tools related to the achievement of sustainable development considering smartness and resilience, to help all Cities and Communities and their interested parties in both rural and urban areas become more sustainable. The proposed series of International Standards will encourage the development and implementation of holistic and integrated approaches to sustainable development and sustainability" (ISO Technical Committee 268, 2012).

The scope of this Standard, as stated by ISO itself, is: "this standard defines and establishes methodologies for a set of indicators to steer and measure the performance of city services and quality of life. It follows the principles set out and can be used in conjunction with ISO 37101, Sustainable development in communities – Management systems – General principles and requirements, when published, and other strategic frameworks. This Standard is applicable to any city, municipality or local government that undertakes to measure its performance in a comparable and verifiable manner, irrespective of size and location." (ABNT NBR ISO 37120:2017).

To determine the level of sustainability of a city, we have used 46 essential (core) indicators provided by the Brazilian version of the *ISO 37120:2017* standard, called "*ABNT NBR ISO 37120:2017 - Sustainable development of communities - Indicators for city services and quality of life*" (ABNT – Brazilian Association for Technical Standards, 2017) – those indicators equal the International Version of the ISO standard. For the standard, those 46 indicators are "core" ones, what means they are a requirement – there are other indicators that are "supporting" indicators, and even though they have interesting approaches for developing countries cities, they will not be used in this article to minimize the amount of data calculated and analyzed (since they are recommendations only). The used indicators are listed below (this article will use the number described at the ISO Standard to numerate each indicator, when applicable, making them easier to be traced by the reader). A table with "core" requirements and their mathematical equation follows their description (Table 1).

i. *Economy Indicators*

- *City's unemployment rate:* A city's unemployment rate (*CUR*) shall be calculated as the number of working-age city residents who during the survey reference period were not in paid employment or self-employment, but available for work, and seeking work (*CRsw*) (numerator) divided by the total labor force (*TLF*) (denominator). The result shall be multiplied by 100 and expressed as a percentage.
- *Assessed value of commercial and industrial properties as a percentage of total assessed value of all properties:* The assessed value of commercial and industrial properties (*AVcip*) as a percentage of total assessed value of all properties shall be expressed as the total assessed value of commercial and industrial properties (*TAVcip*) (numerator) divided by the total assessed value of all properties (*TAVap*) (denominator). The result shall then be multiplied by 100 and expressed as a percentage.
- *Percentage of city population living in poverty:* The percentage of city population living in poverty (*PPlp*) shall be calculated as the number of people living below the poverty threshold (*Pbpt*) (numerator) divided by the total current population of the city (*TCPc*) (denominator). The result shall then be multiplied by 100 and expressed as a percentage.

ii. *Education Indicators*

- *Percentage of female school-aged population enrolled in schools:* The percentage of female school-aged population enrolled in schools (*FSAPeis*) shall be calculated as the number of female school-aged population enrolled at primary and secondary levels in public and private schools

(*FSAPps*) (numerator) divided by the total number of female school-aged population (*TFSAP*) (denominator). The result shall then be multiplied by 100 and expressed as a percentage.

- *Percentage of students completing primary education: survival rate:* The percentage of students completing primary education (*SPEsr*) or survival rate shall be calculated as the total number of students belonging to a school-cohort who complete the final grade of primary education (*SCpe*) (numerator) divided by the total number of students belonging to a school-cohort, i.e. those originally enrolled in the first grade of primary education (*SEfgps*) (denominator). The result shall then be multiplied by 100 and expressed as a percentage. The survival rate of primary education shall be expressed as the percentage of a cohort of students enrolled in the first grade of primary education who reached the final grade of primary education.
- *Percentage of students completing secondary education: survival rate (core indicator):* The percentage of students completing secondary education (*SSEsr*) or survival rate shall be calculated as the total number of students belonging to a school-cohort who complete the final grade of secondary education (*SCse*) (numerator) divided by the total number of students belonging to a school-cohort, i.e. those originally enrolled in the first grade of secondary education (*SEfgss*) (denominator). The result shall then be multiplied by 100 and expressed as a percentage. The survival rate of secondary education shall be expressed as the percentage of a cohort of students enrolled in the first grade of secondary education who reached the final grade of secondary education;
- *Primary education student/teacher ratio (core indicator):* The student/teacher ratio (*STr*) shall be expressed as the number of enrolled primary school students (*PSS*) (numerator) divided by the number of full-time equivalent primary school classroom teachers (*PST*) (denominator). The result shall be expressed as the number of students per teacher".

iii. *Energy*

- *Total residential electrical energy use per capita (kWh/year):* Total residential electrical energy use per capita (*TEUpc*) shall be calculated as the total residential electrical usage of a city in kilowatt hours (*TEUr*) (numerator) divided by the total population of the city (*TPoC*) (denominator). The result shall be expressed as the total residential electrical use per capita in kilowatt hours/year;
- *Percentage of city population with authorized electrical service:* The percentage of city population with authorized electrical service (*PwAES*) shall be calculated as the number of persons in the city with lawful connection to the electrical supply system (*PCEss*) (numerator) divided by the total population of the city (*TPoC*) (denominator). The result shall then be multiplied by 100 and expressed as a percentage;
- *Energy consumption of public buildings per year (kWh/m$^2$):* Energy consumption of public buildings (*ECpb*) shall be calculated per year as the total use of electricity at final consumption stage by public buildings (*TECpb*) (kWh) within a city (numerator) divided by total floor space of these buildings (*TFSpb*) in square meters (m$^2$) (denominator). The result shall be expressed as the total energy consumption of public buildings per year in kilowatt hours per square meter.
- *The percentage of total energy derived from renewable sources, as a share of the city's total energy consumption (core indicator):* The share of a city's total energy consumption derived from renewable sources (*TECrs*) shall be calculated as the total consumption of electricity generated from renewable sources (*TEGrs*) (numerator) divided by total energy consumption (*TEC*) (denominator). The result shall then be multiplied by 100 and expressed as a percentage. Consumption of renewable sources should include geothermal, solar, wind, hydro, tide and wave energy, and combustibles, such as biomass;

iv. *Environment*

- *Fine Particulate Matter (PM2.5) concentration:* Fine Particulate Matter (PM2.5) concentration (*FPMc*) shall be calculated as the total mass of collected particles that are 2.5 microns or less in diameter (*TCFpm*) (numerator) divided by the volume of air sampled (*FVAs*) (denominator). The result shall be expressed as the concentration of PM2.5 in micrograms per standard cubic meter (μg/m$^3$);
- *Particulate Matter (PM10) concentration:* Particulate Matter (PM10) concentration (*PMc*) shall be calculated as the total mass of collected particles in the PM10 size range (*TCpm*) (numerator) divided by the volume of air sampled (*PVAs*) (denominator). The result shall be expressed as the concentration of PM10 in micrograms per standard cubic meter (μg/m$^3$).
- *Greenhouse gas emissions measured in tonnes per capita:* The greenhouse gas emissions measured in tonnes (*GGE*) per capita shall be measured as the total amount of greenhouse gases in tonnes (*TGG*) (equivalent carbon dioxide units) generated over a calendar year by all activities within the city, including indirect emissions outside city boundaries (numerator) divided by the current city population (*TPoC*) (denominator). The result shall be expressed as the total greenhouse gas emissions per capita in tonnes;

v. *Finance*

- *Debt service ratio (debt service expenditure as a percentage of a municipality's own-source revenue):* Debt service ratio is the ratio (*DSR*) of debt service expenditures as a per cent of a municipality's own-source revenue. Debt service ratio shall be calculated as the total long-term debt servicing costs (*TLTDsc*) including lease payments, temporary financing and other debt charges (numerator) divided by total own- source revenue (*CTOR*) (denominator). The result shall then be multiplied by 100 and expressed as a percentage of debt service expenditure as a percent of a municipality's own-source revenue.

vi. *Fire and Emergency Response*

- *Number of firefighters per 100 000 population:* The number of firefighters per 100 000 population (*TFF*) shall be calculated as the total number of paid full-time firefighters (*FTFF*) (numerator) divided by one 100 000$^{th}$ of the city population (denominator). The result shall be expressed as the number of firefighters per 100 000 population.
- *Number of fire-related deaths per 100 000 population:* The number of fire-related deaths per 100 000 population (*TFD*) shall be expressed as the number of deaths directly attributed to a fire incident (*DDAfi*) with death occurring within 30 days. This indicator shall be calculated as the total number of citizen dfire-related deaths recorded in a 12-month period (numerator), divided by one 100 000th of the city's total population (denominator). The result shall be expressed as the number of fire-related deaths per 100 000 population;
- *Number of natural disaster-related deaths per 100 000 population:* The number of natural disaster-related deaths (*NDrd*) per 100 000 population shall be expressed as the number of deaths directly attributed to natural disaster incidents (*DDAnd*). This indicator shall be calculated as the total number of natural disaster-related deaths recorded in a 12-month period (numerator), divided by one 100 000th of the city population (denominator). The result shall be expressed as the number of natural disaster-related deaths per 100 000 population.

vii. *Governance*

- *Voter participation in last municipal election (as a percentage of eligible voters):* The voter participation in the last municipal election (*VPmel*) shall be calculated as the number of persons that voted in the last municipal election (*NPVmel*) (numerator) divided by the city population eligible to vote (*ToCPev*) (denominator). The result shall then be multiplied by 100 and expressed as a percentage;
- *Women as a percentage of total elected to city-level office:* The number of women elected to city-level office (*WEclo*) shall be calculated as the total number of elected city-level positions held by women (*TEWclp*) (numerator) divided by the total number of elected city-level positions (*TEclp*) (denominator). The result shall then be multiplied by 100 and expressed as a percentage;

viii. *(12) Health (group of indicators)*

- *Average life expectancy:* The average life expectancy (*ALEx*) shall be calculated as the average number of years to be lived by a group of people born in the same year, if health and living conditions at the time of their birth remained the same throughout their lives.
- *Number of in-patient hospital beds per 100 000 population:* The number of in-patient hospital beds per 100 000 (*NipHB*) shall be calculated as the total number of in-patient public and private hospital beds (*TNipHB*) (numerator), divided by one 100 000th of the city's total population (denominator). The result shall be expressed as the number of in-patient public and private hospital beds per 100 000 of the city population.
- *Number of physicians per 100 000 population:* The number of physicians per 100 000 population (*NPH*) shall be calculated as the number of general or specialized practitioners whose work-place is in the city (*NPHwc*) (numerator) divided by one 100 000th of the city's total population (denominator). The result shall be expressed as the number of physicians per 100 000 population.
- *Under age five mortality per 1 000 live births:* The underage five mortality per 1 000 live births (*UA5m*) shall refer to the probability of a child born in a specified year dying before reaching the age of five, and shall be expressed as a rate per 1 000 live births.

ix. *Recreation (non-applicable since there is no core indicator in this group)*

x. *Safety*

- *Number of police officers per 100 000 population:* The number of police officers per 100 000 population (*NPof*) shall be calculated as the number of permanent full-time (or full-time equivalent) sworn police officers (*PSPof*) (numerator) divided by one 100 000th of the city's total population (denominator). The result shall be expressed as the number of police officers per 100 000 population.
- *Number of homicides per 100 000 population:* The number of homicides per 100 000 population (*NHmc*) shall be calculated as the number of reported homicides (*NRHmc*) (numerator) divided by one 100 000th of the city's total population (denominator). The result shall be expressed as the number of homicides per 100 000 population.

xi. *Shelter*

- *Percentage of city population living in slums:* The percentage of city population living in slums (*CPLS*) shall be calculated as the number of people living in slums (*NPLS*) (numerator) divided by the city population (*ToCP*) (denominator). The result shall then be multiplied by 100 and expressed as a percentage.

xii. *Solid Waste*

- *Percentage of city population with regular solid waste collection (residential):* The percentage of city population with regular solid waste collection (*CPrsw*) shall be calculated as the number of people within the city that are served by solid waste collection (*NPCswc*) (numerator) divided by the total city population (*ToCP*) (denominator). The result shall then be multiplied by 100 and expressed as a percentage.
- *Total collected municipal solid waste per capita:* The total collected municipal solid waste (*TCMsw*) per capita shall be expressed as the total municipal solid waste produced in the municipality per person. This indicator shall be calculated as the total amount of solid waste (household and commercial) generated in tonnes (*TASWhc*) (numerator) divided by the total city population (*ToCP*) (denominator). The result shall be expressed as total municipal solid waste collected per capita in tonnes.
- *Percentage of the city's solid waste that is recycled:* The percentage of the city's solid waste that is recycled (*CrSW*) shall be calculated as the total amount of the city's solid waste that is recycled in tonnes (*TCrSW*) (numerator) divided by the total amount of solid waste produced in the city in tonnes (*TSWpc*) (denominator). The result shall then be multiplied by 100 and expressed as a percentage.

xiii. *Telecommunications and Innovation*

- *Number of internet connections per 100 000 population:* The number of internet connections per 100 000 population (*NIntC*) shall be calculated as the number of internet connections in the city (*NIntCc*) (numerator) divided by one 100 000th of the city's total population (denominator). The result shall be expressed as the number of internet connections per 100 000 population.
- *Number of cell phone connections per 100 000 population:* The number of cell phone connections per 100 000 (*NoCPC*) shall be calculated as the total number of cell phone connections in the city (*NoCPCc*) (numerator) divided by one 100 000th of the city's total population (denominator). The result shall be expressed as the number of cell phone connections per 100 000 population.
- *Number of landline phone connections per 100 000 population:* The number of landline phone connections per 100 000 (*NoLPC*) shall be calculated as the total number of landline telephone connections in the city (*NoLPCc*) (numerator) divided by one 100 000th of the city's total population (denominator). This result shall be expressed as the number of landline connections per 100 000 population.

xiv. *Transportation*

- *Kilometers of high capacity public transport system per 100 000 population:* The Kilometers of high capacity public transport system per 100 000 population (*KHCpts*) shall be calculated by adding the Kilometers of high capacity public transport systems operating within the city (*KHCptsc*) (numerator) divided by one 100 000th of the city's total population (denominator). The result shall be expressed as the Kilometers of high capacity public transport system per 100 000 population.
- *Kilometers of light passenger public transport system per 100 000 population:* The Kilometers of light passenger public transport system (*KLPpts*) per 100 000 population shall be calculated by adding the Kilometers of light passenger transport systems provided within the city (*KLPptsc*) (numerator), divided by one 100 000th of the city's total population (denominator). The result shall be expressed as the Kilometers of light passenger transport system per 100 000 population. Expressed as per 100 000 population.
- *Annual number of public transport trips per capita:* Annual number of public transport trips per capita (*PTTpc*) shall be calculated as the total annual number of transport trips originating in the city (*NTToic*) - "ridership of public transport" - (numerator), divided by the total city population (*ToCP*) (denominator). The result shall be expressed as the annual number of public transport trips per capita.
- *Number of personal automobiles per capita:* The number of personal automobiles per capita (*PAPc*) shall be calculated as the total number of registered personal automobiles in a city (*RPAc*) (numerator) divided by the total city population (*ToCP*) (denominator). The result shall be expressed as the number of personal automobiles per capita.

xv. *Urban Planning*

- *Green area (hectares) per 100 000 population:* Green area (hectares) per 100 000 population (*GEHct*) shall be calculated as the total area (in hectares) of green in the city (*TAGc*) (numerator) divided by one 100 000th of the city's total population (denominator). The result shall be expressed in hectares of green area per 100 000 population.

xvi. *Wastewater*

- *Percentage of city population served by wastewater collection:* Percentage of city population served by wastewater collection (*PSWWc*) shall be calculated as the number of people within the city that are served by wastewater collection (*PSWWcic*) (numerator) divided by the city population (*ToCP*) (denominator). The result shall then be multiplied by 100 and expressed as a percentage.

- *Percentage of the city's wastewater that has received no treatment:* Percentage of the city's wastewater that has received no treatment (*PWWnt*) shall be calculated as the total amount of the city's wastewater that has undergone no treatment (*TWWnt*) (numerator) divided by the total amount of wastewater produced in the city and collected (*TWWpc*) (denominator). This result shall then be multiplied by 100 and expressed as a percentage.
- *Percentage of the city's wastewater receiving primary treatment:* The percentage of the city's wastewater receiving primary treatment (*PWWpt*) shall be calculated as the total amount of the city's wastewater that has undergone primary treatment (*TWWpt*) (numerator) divided by the total amount of wastewater produced in the city and collected (*TWWpc*) (denominator). This result is then multiplied by 100 and expressed as a percentage of the city's wastewater receiving primary treatment.
- *Percentage of the city's wastewater receiving secondary treatment:* Percentage of the city's wastewater receiving secondary treatment (*PWWst*) shall be calculated as the total amount of the city's wastewater that has undergone secondary treatment (*TWWst*) (numerator) divided by the total amount of wastewater produced in the city and collected (*TWWpc*) (denominator). The result shall then be multiplied by 100 and expressed as a percentage.
- *Percentage of the city's wastewater receiving tertiary treatment:* Percentage of the city's wastewater receiving tertiary treatment (*PWWtt*) shall be calculated as the total amount of the city's wastewater that has undergone tertiary treatment (*TWWtt*) (numerator) divided by the total amount of wastewater produced in the city and collected (*TWWpc*) (denominator). The result shall then be multiplied by 100 and expressed as a percentage;

xvii. *Water and Sanitation*

- *Percentage of city population with potable water supply service:* The percentage of city population with potable water supply service (*PPWs*) shall be calculated as the total number of people with potable water supply service (*TPPWs*) (numerator) divided by total city population (*ToCP*) (denominator). The result shall then be multiplied by 100 and expressed as a percentage of city population serviced by a potable water supply service.
- *Percentage of city population with sustainable access to an improved water source:* The percentage of city population with sustainable access to an improved water source (*PSAiws*) shall be calculated as the total population with access to an improved water source (*TPAiws*) (numerator) divided by the total city population (*ToCP*) (denominator). The result shall then be multiplied by 100 and expressed as a percentage.
- *Percentage of population with access to improved sanitation:* The percentage of population with access to improved sanitation (*PAAis*) shall be calculated as the total number of people using improved sanitation facilities (*TPAis*) (numerator) divided by the total city population (*ToCP*) (denominator). The result shall then be multiplied by 100 and expressed as a percentage.
- *Total domestic water consumption per capita (liters/day):* The total domestic water consumption per capita (*TDWCc*) shall be calculated as the total amount of the city's water consumption in liters per day for domestic use (*TDWC*) (numerator) divided by the total city population (*ToCP*) (denominator). The result shall be expressed as the total domestic water consumption per capita in liters per day.

*Table 1:* ISO 37120 Standard's Core Indicators and its Equations

| (ISO's Indicator Number) Indicator | Equation |
|---|---|
| (5.1) City's unemployment rate | Q5.1=CRU= CRswTLF x 100 |
| (5.2) Assessed value of commercial and industrial properties as a percentage of total assessed value of all properties | Q5.2=AVcip= TAVcipTAVap x 100 |
| (5.3) Percentage of city population living in poverty | Q5.3=PPlp= PbptTCPc x 100 |
| (6.1) Percentage of female school-aged population enrolled in schools | Q6.1=FSAPeis= FSAPpsTFSAP x 100 |
| (6.2) Percentage of students completing primary education: survival rate | Q6.2=SPEsr= SCpeSEfgps x 100 |
| (6.3) Percentage of students completing secondary education: survival rate | Q6.3=SSEsr= SCseSEfgss x 100 |
| (6.4) Primary education student/teacher ratio | Q6.4=STr= PSSPST |
| (7.1) Total residential electrical energy use per capita (kWh/year) | Q7.1=TEUpc= TEUrTPoC |
| (7.2) Percentage of city population with authorized electrical service | Q7.2=PwAES= PCEssTPoC x 100 |
| (7.3) Energy consumption of public buildings per year (kWh/$m^2$) | Q7.3=ECpb= TECpbTFSpb |
| (7.4) The percentage of total energy derived from renewable sources, as a share of the city's total energy consumption | Q7.4=ECpb= TECrsTEC |
| (8.1) Fine Particulate Matter (PM2.5) concentration | Q8.1=FPMc= TCFpmFVAs |

| | |
|---|---|
| (8.2) Particulate Matter (PM10) concentration | Q8.2=PMc= TCpmPVAs |
| (8.3) Greenhouse gas emissions measured in tonnes per capita | Q8.3=TGGE= TGGTPoC |
| (9.1) Debt service ratio (debt service expenditure as a percentage of a municipality's own-source revenue) | Q9.1=DSR= TLTDscCTOR x 100 |
| (10.1) Number of firefighters per 100 000 population | Q10.1=TGGE= TGGTPoC100 000 |
| (10.2) Number of fire-related deaths per 100 000 population | Q10.2=TFD= DDAfiTPoC100 000 |
| (10.3) Number of natural disaster-related deaths per 100 000 population | Q10.3=NDrd= DDAndTPoC100 000 |
| (11.1) Voter participation in last municipal election (as a percentage of eligible voters) | Q11.1=VPmel= NPVmelToCPev x 100 |
| (11.2) Women as a percentage of total elected to city-level office | Q11.2=WEclo= TEWclpTEclp x 100 |
| (12.1) Average life expectancy | *N/A* |
| (12.2) Number of in-patient hospital beds per 100 000 population | Q12.2=NipHB= TNipHBTPoC100 000 |
| (12.3) Number of physicians per 100 000 population | Q12.3=NPH= NPHwcTPoC100 000 |
| (12.4) Under age five mortality per 1 000 live births | *N/A* |
| (14.1) Number of police officers per 100 000 population | Q14.1=NPof= PSPofTPoC100 000 |
| (14.2) Number of homicides per 100 000 population | Q14.2=NHmc= NRHmcTPoC100 000 |
| (15.1) Percentage of city population living in slums | Q15.1=CPLS= NPLSToCP x 100 |
| (16.1) Percentage of city population with regular solid waste collection (residential) | Q16.1=CPrsw= NPCswcToCP x 100 |
| (16.2) Total collected municipal solid waste per capita | Q16.2=TCMsw= TASWhcToCP |
| (16.3) Percentage of the city's solid waste that is recycled | Q16.3=CrSW= TCrSWTSWpc x 100 |
| (17.1) Number of internet connections per 100 000 population | Q17.1=NIntC= NIntCcTPoC100 000 |
| (17.2) Number of cell phone connections per 100 000 population | Q17.2=NoCPC= NoCPCcTPoC100 000 |
| (18.1) Kilometers of high capacity public transport system per 100 000 population | Q18.1=KHCpts= KHCptscTPoC100 000 |
| (18.2) Kilometers of light passenger public transport system per 100 000 population | Q18.2=KLPpts= KLPptscTPoC100 000 |
| (18.3) Annual number of public transport trips per capita | Q18.3=PTTpc= NTToicToCP |
| (18.4) Number of personal automobiles per capita | Q18.4=PAPc= RPAcToCP |
| (19.1) Green area (hectares) per 100 000 population | Q19.1=GEHct= TAGcTPoC100 000 |
| (20.1) Percentage of city population served by wastewater collection | Q20.1=PSWWc= PSWWcicToCP x 100 |
| (20.2) Percentage of the city's wastewater that has received no treatment | Q20.2=PWWnt= TWWntTWWpc x 100 |
| (20.3) Percentage of the city's wastewater receiving primary treatment | Q20.3=PWWpt= TWWptTWWpc x 100 |
| (20.4) Percentage of the city's wastewater receiving secondary treatment | Q20.4=PWWst= TWWstTWWpc x 100 |
| (20.5) Percentage of the city's wastewater receiving tertiary treatment | Q20.5=PWWtt= TWWttTWWpc x 100 |
| (21.1) Percentage of city population with potable water supply service | Q21.1=PPWs= TPPWsToCP x 100 |
| (21.2) Percentage of city population with sustainable access to an improved water source | Q21.2=PSAiws= TPAiwsToCP x 100 |
| (21.3) Percentage of population with access to improved sanitation | Q21.3=PAAis= TPAisToCP x 100 |
| (21.4) Total domestic water consumption per capita (liters/day) | Q21.4=TDWCc= TDWCToCP |

On the next table (Table 2) there are all core indicators values of the chosen cities to test the model. As mentioned, all the information has been collected from WCCD, and was the latest available at the Portal by the time of this article writing.

*Table 2:* City Core Indicator's Values collected from WWCD Open Data Portal

| Indicator | Tbilisi | Guadalajara | Boston | London |
|---|---|---|---|---|
| Economy | | | | |
| City's unemployment rate | 21.38% | 3.75% | 3.37% | 5.99% |
| Assessed value of commercial and industrial properties as a percentage of total assessed value of all properties | 20.02% | 34.02% | 31.00% | 16.15% |
| Percentage of city population living in poverty | 11.10% | 36.26% | 20.99% | 25.77% |
| Education | | | | |
| Percentage of female school-aged population enrolled in schools | 101.31% | 91.08% | 96.90% | 98.17% |
| Percentage of students completing primary education: survival rate | 95.23% | 96.79% | 100.00% | 100.00% |
| Percentage of students completing secondary education: survival rate | 73.85% | 85.86% | 76.00% | 101.59% |
| Primary education student/teacher ratio | 66.48 | 30.00 | 14.50 | 20.87 |

| | | | | |
|---|---|---|---|---|
| **Energy** | | | | |
| Total residential electrical energy use per capita (kWh/year) | 878.07 | 355.73 | 1,971.00 | 1,556.70 |
| Percentage of city population with authorized electrical service | 100.00% | 99.59% | 100.00% | 100.00% |
| Energy consumption of public buildings per year (kWh/m$^2$) | 19.49 | 137.67 | 110.60 | 172.00 |
| The percentage of total energy derived from renewable sources, as a share of the city's total energy consumption | 19.32% | 15.41% | 15.00% | 2.03% |
| **Environment** | | | | |
| Fine Particulate Matter (PM2.5) concentration | 26.30 | 21.26 | 6.51 | 14.20 |
| Particulate Matter (PM10) concentration | 49.30 | 43.98 | 12.53 | 19.30 |
| Greenhouse gas emissions measured in tonnes per capita | 3.03 | 3.27 | 9.60 | 4.89 |
| **Finance** | | | | |
| Debt service ratio (debt service expenditure as a percentage of a municipality's own-source revenue) | 1.96% | 86.63% | 6.40% | 7.52% |
| **Fire & Emergency** | | | | |
| Number of firefighters per 100 000 population | 61.81 | 22.5 | 220.4 | 59.85 |
| Number of fire-related deaths per 100 000 population | 1.35 | 0.06 | 0.76 | 0.34 |
| Number of natural disaster-related deaths per 100 000 population | 1.98 | 0.00 | 0.00 | 0.00 |
| **Governance** | | | | |
| Voter participation in last municipal election (as a percentage of eligible voters) | 37.04% | 50.00% | 13.63% | 38.65% |
| Women as a percentage of total elected to city-level office | 24.00% | 41.98% | 28.60% | 30.77% |
| **Health** | | | | |
| Average life expectancy | 72.90 | 75.70 | 80.00 | 82.05 |
| Number of in-patient hospital beds per 100 000 population | 664.78 | 97.30 | 894.86 | 266.80 |
| Number of physicians per 100 000 population | 1,405.66 | 219.72 | 1,153.32 | 279.30 |
| Under age five mortality per 1 000 live births | 9.20 | 17.60 | 5.68 | 4.37 |
| **Safety** | | | | |
| Number of police officers per 100 000 population | 156.96 | 137.18 | 324.10 | 371.94 |
| Number of homicides per 100 000 population | 4.13 | 16.11 | 6.69 | 1.14 |
| **Shelter** | | | | |
| Percentage of city population living in slums | 1.17% | 7.26% | 0.52% | 0.35% |
| **Solid Waste** | | | | |
| Percentage of city population with regular solid waste collection (residential) | 100.00% | 99.01% | 100.00% | 100.00% |
| Total collected municipal solid waste per capita | 0.35 | 0.36 | 0.32 | 0.43 |
| Percentage of the city's solid waste that is recycled | 0.00% | 8.00% | 20.70% | 30.56% |
| **Telecom & Innovation** | | | | |
| Number of internet connections per 100 000 population | 29,161.99 | 12,086.00 | 72,423.18 | 32,164.00 |
| Number of cell phone connections per 100 000 population | 133,029.83 | 100,002.51 | 185,401.14 | 139,170.98 |
| **Transportation** | | | | |
| Kilometers of high capacity public transport system per 100 000 population | 4.82 | 0.82 | 12.12 | 14.10 |
| Kilometers of light passenger public transport system per 100 000 population | 401.35 | 263.63 | 78.49 | 49.29 |
| Annual number of public transport trips per capita | 327.31 | 29.30* | 404.46 | 563.03 |
| Number of personal automobiles per capita | 0.47 | 0.30 | 0.27 | 0.30 |
| **Urban Planning** | | | | |
| Green area (hectares) per 100 000 population | 1,306.78 | 18.05 | 241.96 | 871.89 |
| **Wastewater** | | | | |
| Percentage of city population served by wastewater collection | 85.87% | 98.67% | 100.00% | 100.00% |
| Percentage of the city's wastewater that has received no treatment | 0.00% | 45.76% | 0.00% | 0.00% |
| Percentage of the city's wastewater receiving primary treatment | 100.00% | 54.24% | 100.00% | 100.00% |
| Percentage of the city's wastewater receiving secondary treatment | 100.00% | 40.40% | 100.00% | 100.00% |
| Percentage of the city's wastewater receiving tertiary treatment | 0.00% | 13.84% | 100.00% | 100.00% |

| | | | | |
|---|---|---|---|---|
| Water And Sanitation | | | | |
| Percentage of city population with potable water supply service | 93.22% | 97.98% | 100.00% | 100.00% |
| Percentage of city population with sustainable access to an improved water source | 93.22% | 98.29% | 100.00% | 100.00% |
| Percentage of population with access to improved sanitation | 87.57% | 85.33% | 99.48% | 100.00% |
| Total domestic water consumption per capita (liters/day) | 317.15 | 202.68 | 144.66 | 164.41 |

*c) SAFE Model*

Developed by Yannis A. Phillis and Luc A. Andriantiatsaholiniaina (2011) in their article "Sustainability: an ill-defined concept and its assessment using fuzzy logic", the SAFE (Sustainability Assessment by Fuzzy Evaluation) model "provides a mechanism for measuring development sustainability". As informed by the authors: (1) The output of the model is a degree (%) of sustainability of the system under examination (locality, state, country, etc.); (2) The model is open to new inputs as reality and experience change, and it weighs all inputs according to their impact; (3) It should be stressed that this method in itself is both a new definition and numerical assessment of sustainability. The two main differences between the SAFE model and the adapted SAFE model we are using are: (a) the indicators used in our model are different from SAFE, and (b) we have simplified the number of fuzzy variables, making more feasible for cities from developing countries to analyze their data. The SAFE model has been chosen because of its flexibility and applicability, and even though we foresee its feasibility, we decided to reduce some layers of the model, "creating" a simpler configuration to address the less complete and advanced data from developing countries cities. The adapted SAFE model can be graphically understood through Figure 1.

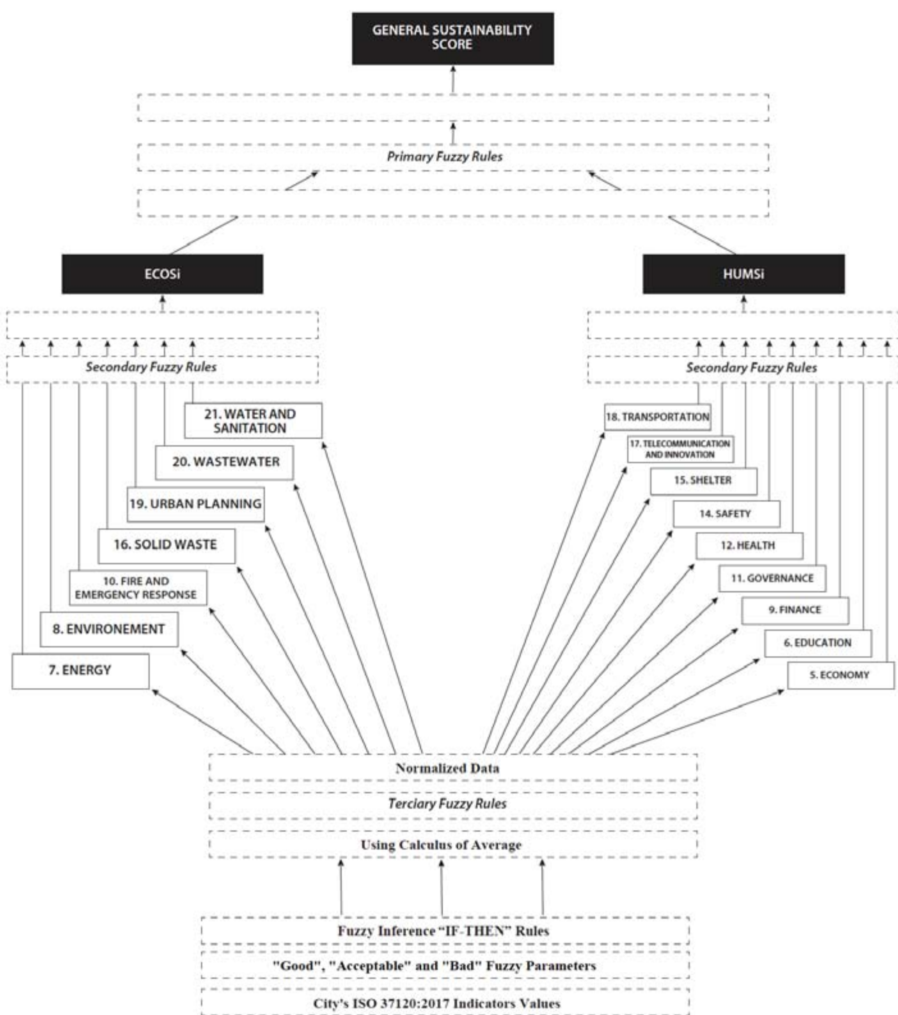



*Fig. 1:* Methodology for SAFE Model Adapted to Support ISO 37120 Indicators

i. *Fuzzy Rules used in the Model*

At the 'Tertiary Fuzzy Rules' we have established three ranges of fuzzy parameters (Table 3) to be used with each indicator value: "GOOD", "ACCEPTABLE" and "BAD". Those parameters intervals have been estimated through observation by specialists in each kind of indicator, based on the data collected from WCCD Open Data Portal – fuzzy logic uses expert knowledge to define linguistic variables and rules (Phillis e Andrian-tiatsaholiniaina, 2001).

After running the Fuzzy Logic for each group of indicators - i.e. from 5 (Economy) to 21 (Water and Sanitation) -, the "defuzzification" of each group result was treated through 'Secondary Fuzzy Rules', when we normalized the data in a scale from 0 to 100, being 0 to 29.9 (BAD), 30 to 59.9 (ACCEPTABLE) and 60 to 100 (GOOD).

After that, we have got two Fuzzy value 'groups': HUMSi (for the Human- related variables) and ECOSi (for the Ecological related variables). Those results have been "defuzzified" and then treated through 'Primary Fuzzy Rules' to get the "General Sustainability Score";

*HUMSi* encompasses these groups of indicators: *Economy, Education, Finance, Governance, Shelter, Health, Safety, Telecommunications and Innovation* and *Transportation*;

*ECOSi* encompasses these groups of indicators: *Energy, Environment, Fire and Emergency Response, Solid Waste, Urban Planning* and *Water and Sanitation*;

*Table 3:* Fuzzy parameters for each ISO 37.120 Indicator

| Indicator | Fuzzy Parameter | | |
|---|---|---|---|
| | GOOD | ACCEPTABLE | BAD |
| **Economy** | | | |
| City's unemployment rate | 0 - 5 | > 5 ≤ 10 | > 10 |
| Assessed value of commercial and industrial properties as a percentage of total assessed value of all properties | > 40 | > 20 ≤ 40 | 0 - 20 |
| Percentage of city population living in poverty | 0 - 20 | > 20 ≤ 40 | > 40 |
| **Education** | | | |
| Percentage of female school-aged population enrolled in schools | > 80 | > 50 ≤ 80 | 0 - 50 |
| Percentage of students completing primary education: survival rate | > 80 | > 50 ≤ 80 | 0 - 50 |
| Percentage of students completing secondary education: survival rate | > 60 | > 30 ≤ 60 | 0 - 30 |
| Primary education student/teacher ratio | 0 - 20 | > 20 ≤ 30 | > 30 |
| **Energy** | | | |
| Total residential electrical energy use per capita (kWh/year) | > 1000 | > 500 ≤ 1000 | 0 - 500 |
| Percentage of city population with authorized electrical service | > 90 | > 80 ≤ 90 | 0 – 80 |
| Energy consumption of public buildings per year (kWh/m$^2$) | > 200 | > 100 ≤ 200 | 0 - 100 |
| The percentage of total energy derived from renewable sources, as a share of the city's total energy consumption | >40 | > 20 ≤ 40 | 0 - 20 |
| **Environment** | | | |
| Fine Particulate Matter (PM2.5) concentration | 0 - 10 | > 10 ≤ 20 | > 20 |
| Particulate Matter (PM10) concentration | 0 - 25 | > 25 ≤ 50 | > 50 |
| Greenhouse gas emissions measured in tonnes per capita | 0 - 8 | > 8 ≤ 12 | > 12 |
| **Finance** | | | |
| Debt service ratio (debt service expenditure as a percentage of a municipality's own-source revenue) | 0 - 20 | > 20 ≤ 50 | > 50 |
| **Fire & Emergency** | | | |
| Number of firefighters per 100 000 population | > 40 | > 20 ≤ 40 | 0 - 20 |
| Number of fire-related deaths per 100 000 population | 0 - 0,5 | > 0,5 ≤ 1 | > 1 |
| Number of natural disaster-related deaths per 100 000 population | 0 - 0,5 | > 0,5 ≤ 1 | > 1 |
| **Governance** | | | |
| Voter participation inlast municipal election (as a percentage of eligible voters) | > 70 | > 50 ≤ 70 | 0 - 50 |
| Women as a percentage of total elected to city-level office | > 50 | > 30 ≤ 50 | 0 - 30 |
| **Health** | | | |
| Average life expectancy | > 80 | > 70 ≤ 80 | 0 - 70 |
| Number of in-patient hospial beds per 100 000 population | > 300 | > 200 ≤ 300 | 0 - 200 |
| Number of physicians per 100 000 population | > 200 | > 100 ≤ 200 | 0 – 100 |
| Under age five mortality per 1 000 live births | 0 - 5 | > 100 ≤ 200 | 0 - 100 |

| | | | |
|---|---|---|---|
| Safety<br>Number of police officers per 100 000 population<br>Number of homicides per 100 000 population | > 200<br>0 - 5 | > 100 ≤ 200<br>> 5 ≤ 10 | 0 - 100<br>> 10 |
| Shelter<br>Percentage of city population living in slums | 0 - 5 | > 5 ≤ 10 | > 10 |
| Solid Waste<br>Percentage of city population with regular solid waste collection (residential)<br>Total collected municipal solid waste per capita<br>Percentage of the city's solid waste that is recycled | > 95<br>> 0,3<br>> 50 | > 90 ≤ 95<br>> 0,15 ≤ 0,3<br>> 30 ≤ 50 | 0 - 90<br>0 - 0,15<br>0 - 30 |
| Telecom. & Innov.<br>Number of internet connections per 100 000 population<br>Number of cell phone connections per 100 000 population | > 20 000<br>>100 000 | > 10 000 ≤ 20 000<br>> 80 000≤ 100 000 | 0 – 10 000<br>0 – 80 000 |
| Transportation<br>Kilometers of high capacity public transport system per 100 000 population<br>Kilometers of light passenger public transport system per 100 000 population<br>Annual number of public transport trips per capita<br>Number of personal automobiles per capita | > 14<br>> 200<br>> 400<br>0 - 0,25 | > 7 ≤ 14<br>> 100 ≤ 200<br>> 200 ≤ 400<br>> 0,25 ≤ 0,4 | 0 – 7<br>0 – 100<br>0 – 200<br>> 0,4 |
| Urban Planning<br>Green area (hectares) per 100 000 population | > 200 | > 100 ≤ 200 | 0 - 100 |
| Wastewater<br>Percentage of city population served by wastewater collection<br>Percentage of the city's wastewater that has received no treatment<br>Percentage of the city's wastewater receiving primary treatment<br>Percentage of the city's wastewater receiving secondary treatment<br>Percentage of the city's wastewater receiving tertiary treatment | > 90<br>0 - 10<br>> 90<br>> 70<br>> 50 | > 80 ≤ 90<br>> 10 ≤ 20<br>> 70 ≤ 90<br>> 50 ≤ 70<br>> 30 ≤ 50 | 0 – 80<br>> 20<br>0 – 70<br>0 - 50<br>0 - 30 |
| Water & Sanitation<br>Percentage of city population with potable water supply service<br>Percentage of city population with sustainable access to an improved water source<br>Percentage of population with access to improved sanitation<br>Total domestic water consumption per capita (liters/day) | > 95<br>> 95<br>> 95<br>> 200 | > 90 ≤ 95<br>> 90 ≤ 95<br>> 90 ≤ 95<br>> 150 ≤ 200 | 0 - 90<br>0 - 90<br>0 - 90<br>0 – 150 |

ii. *Fuzzy Calculi*

To calculate data using the adapted SAFE Model logic, we have developed an algorithm in *Python* language (https://www.python.org/) under *Anaconda Python Data Science Platform* (https://www. anaconda. com). We decided to do this, instead of using *ready-to-use* mathematical platforms, for the flexibility we have gained on the way of adding more variables and rules in the future. We also have used *Scikit-fuzzy* library (https://github.com/scikit-fuzzy/scikit-fuzzy) with Python for the fuzzy logic process (Python, Anaconda, Github and Scikit are trademarks of their owners).

Fuzzy equations were not described in this article, since there is plenty of literature on the subject – in any case, to have a deep view of the equations, you can refer to Yannis et al. (2011).

iii. *Graph*

The adapted SAFE Model calculi will generate graphics that can be interpreted this way (Fig 2):

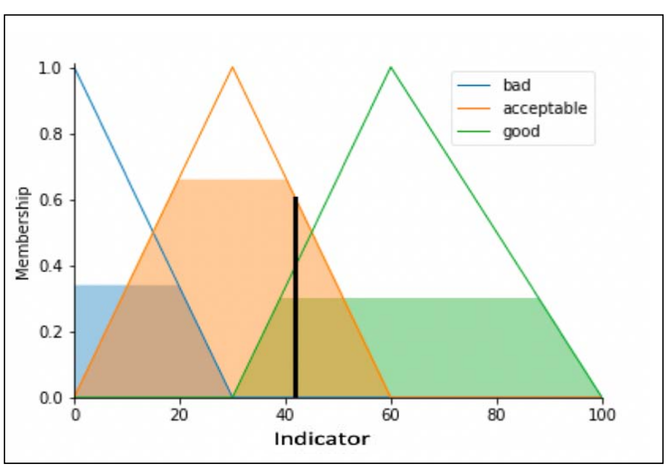



*Fig. 2:* Fuzzy output graph for a given group of indicators

- The first triangle (from left to right) shows the fuzzy "BAD" range;
- The second triangle (from left to right) shows the fuzzy "ACCEPTABLE" range;
- The third triangle (from left to right) shows the fuzzy "GOOD" range;
- The height of the solid area in the first triangle shows "how bad" the Indicator is;
- The height of the solid area in the second triangle shows "how acceptable" the Indicator is;
- The height of the solid area in the third triangle shows "how good" the Indicator is;
- The black vertical line shows the actual CRISP Value (calculated numeric value resulting from the defuzzification process) of the group of indicators;
- The height of the black vertical line shows how relevant (to the overall fuzzy result) the crisp value is.

## III. Results

Through the adapted SAFE Model Fuzzy calculi, we have been able to determine a global score number, at the end of the fuzzy rules, that can be seen in the next table (Table 4).

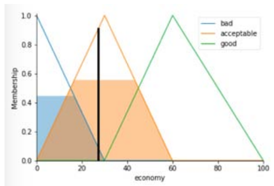
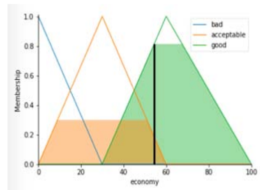
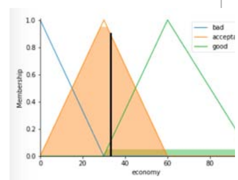
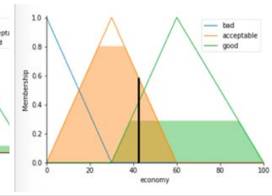
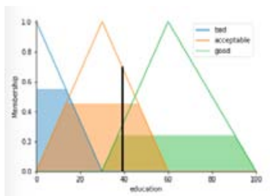
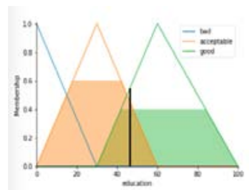
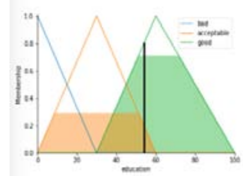
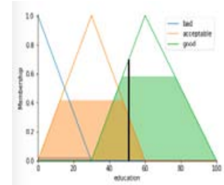
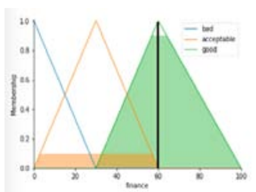
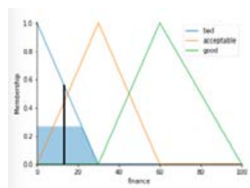
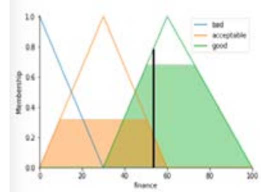
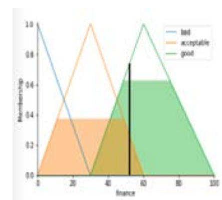
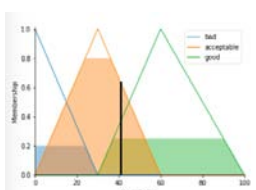
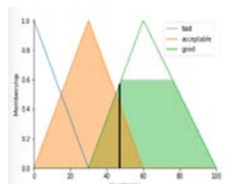
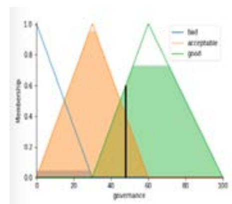
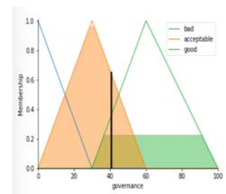
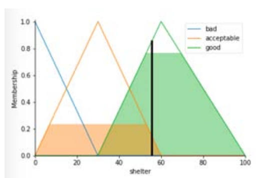
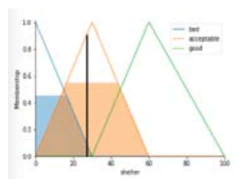
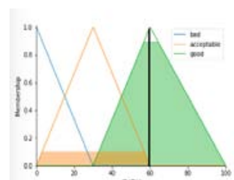
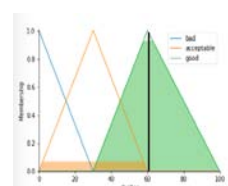
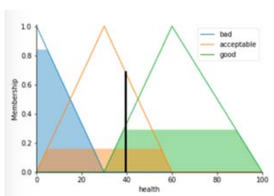
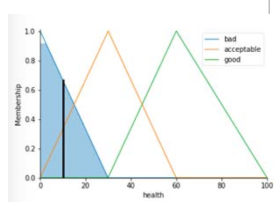
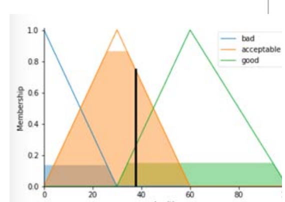
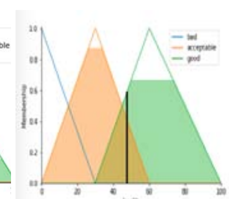
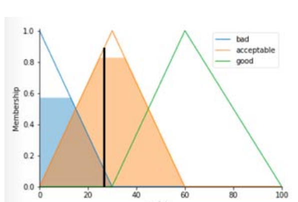
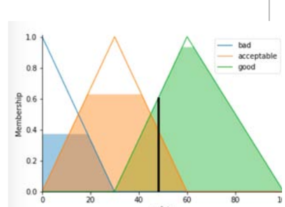
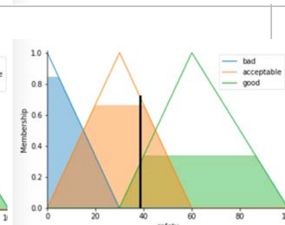
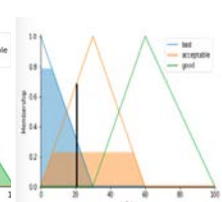
- To Tbilisi, the calculated general score was: *26.4882*
- To Guadalajara, the calculated general score was: *26.4584*
- To Boston, the calculated general score was: *47.1025*
- To London, the calculated general score was: *47.0857*

*Table 4:* SAFE Model Calculi Results

| | Tbilisi (GEO) | Guadalajara (MEX) | Boston (USA) | London (UK) |
|---|---|---|---|---|
| Indicator | HUMSi | | | |
| 5 Economy | 27.2329 | 54.2042 | 33.0121 | 42.5339 |
| 6. Education | 30.0279 | 46.2247 | 54.1088 | 50.8832 |
| 9. Finance | 59.6755 | 13.0576 | 53.3368 | 51.9278 |
| 11.Governance | 40.9456 | 46.9240 | 47.7288 | 40.4772 |
| 15. Shelter | 55.6007 | 27.0628 | 59.4777 | 60.6362 |
| 12. Health | 39.3827 | 10.0341 | 37.6115 | 47.5721 |
| 14. Safety | 26.5344 | 47.9997 | 38.4643 | 20.4454 |
| 17. Telco & Innovation | 45.5658 | 47.5484 | 43.1992 | 45.3375 |
| 18. Transportation | 47.5852 | 47.3632 | 48.2151 | 47.8583 |
| Calculated HUMSi: | 29.9590 | 29.9604 | 51.7908 | 52.4961 |
| Indicator | ECOSi | | | |
| 7. Energy | 27.0407 | 26.1312 | 26.0261 | 15.6583 |
| 8. Environment | 44.4931 | 44.6521 | 42.8161 | 45.9163 |
| 10. Fire & Emergency | 47.4968 | 36.8213 | 63.6628 | 63.3044 |
| 16. Solid Waste | 9.9686 | 21.6357 | 28.6053 | 31.7512 |
| 19. Urban Planning | 63.3363 | 18.9522 | 63.2986 | 63.3130 |
| 20. Wastewater | 9.9686 | 25.7874 | 64.7161 | 64.7161 |
| 21. Water & Sanitation | 53.1570 | 63.2986 | 29.9483 | 36.7871 |
| Calculated ECOSi: | 48.4515 | 48.5864 | 47.0019 | 49.6479 |
| Calculated General Score: | 26.4882 | 26.4584 | 47.1025 | 47.0857 |

Those calculi have generated graphics, as the one explained on Figure 2, that show the degree of membership of each crisp value (for each indicator). On the next table (Table 5) you will find all ISO 37120 indicators with their fuzzy number and graphic calculated. You will also find the tertiary, secondary and primary fuzzy rules (described on figure 1), all depicted on graphics – those graphics are disposed in columns (that determine the city) and lines (that determine the indicator). At line 22 of Table 5, you will finally find the global score for each city.

*Table 5:* Adapted SAFE Model fuzzy calculi graphic results for each city

| | CITY: | TBILISI | GUADALAJARA | BOSTON | LONDON |
|---|---|---|---|---|---|
| | INDICATOR | A | B | C | D |
| 1 | Economy |  |  |  |  |
| 2 | Education |  |  |  |  |
| 3 | Finance |  |  |  |  |
| 4 | Governance |  |  |  |  |
| 5 | Shelter |  |  |  |  |
| 6 | Health |  |  |  |  |
| 7 | Safety |  |  |  |  |

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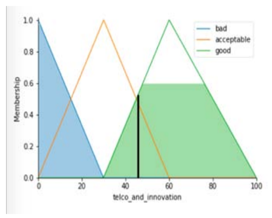
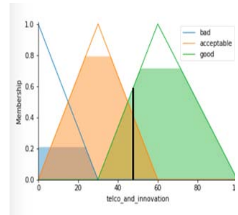
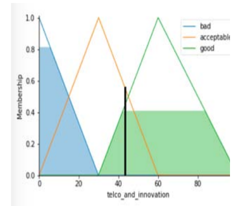
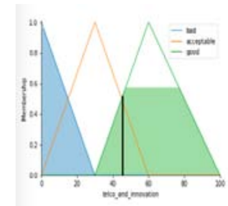
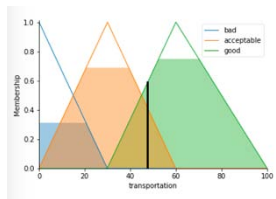
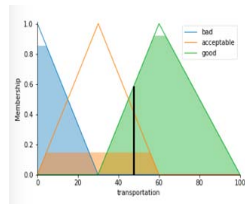
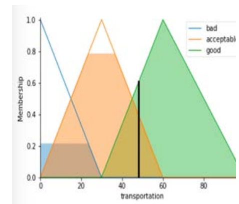
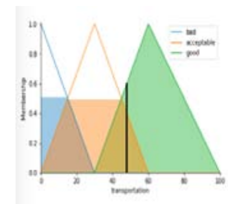
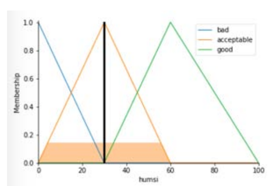
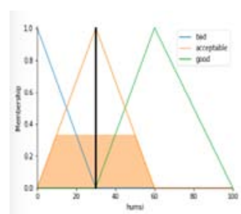
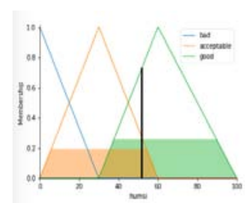
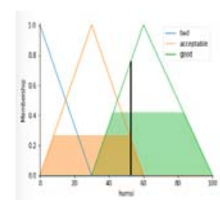
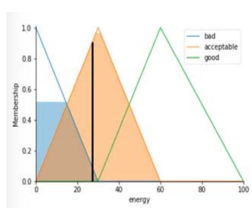
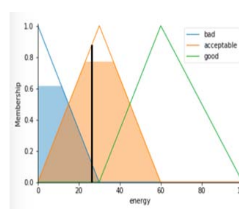
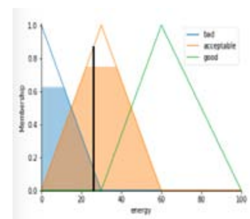
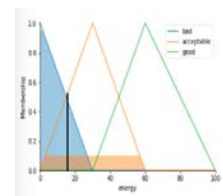
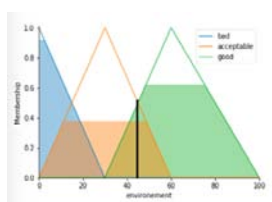
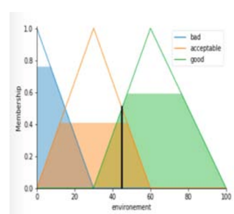
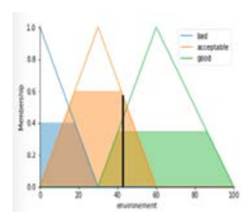
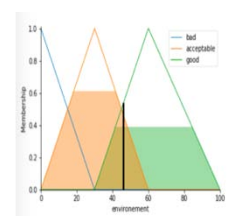
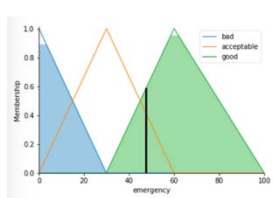
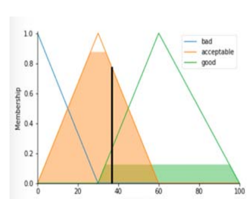
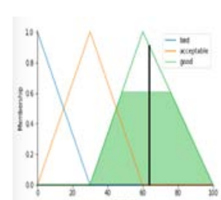
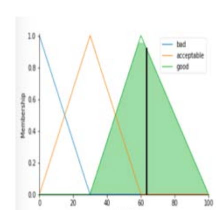
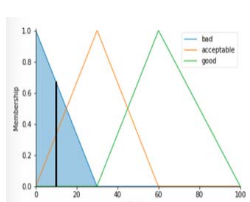
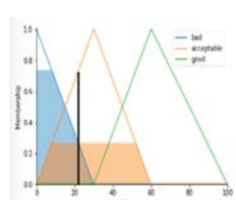
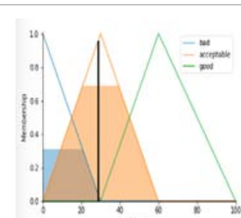
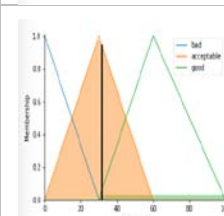
| 8 | Telecom. and Innovation |  |  |  |  |
| 9 | Transport. |  |  |  |  |
| 10 | HUMSi |  |  |  |  |
| 11 | HUMSi Crisp Value | 29.9590 | 29.9604 | 51.7908 | 52.4961 |
| 12 | Energy |  |  |  |  |
| 13 | Environment |  |  |  |  |
| 14 | Fire and Emergency |  |  |  |  |
| 15 | Solid Waste |  |  |  |  |

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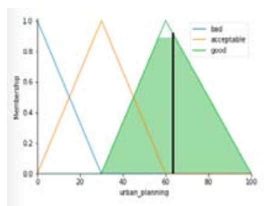
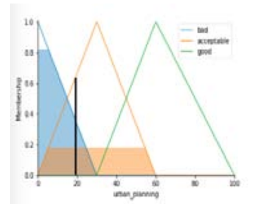
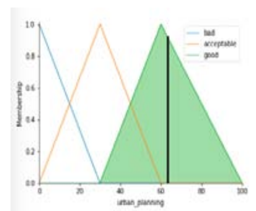
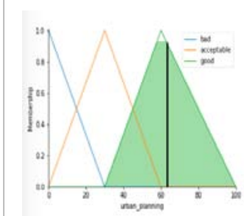
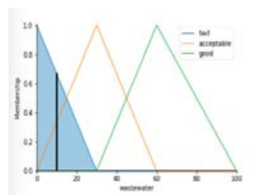
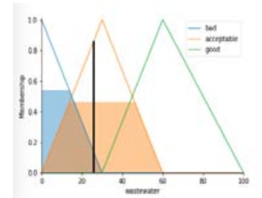
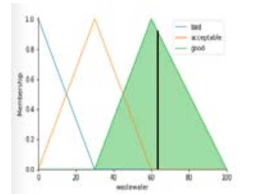
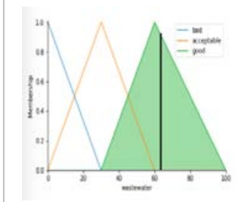
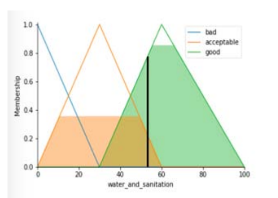
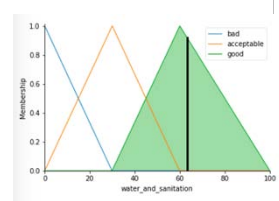
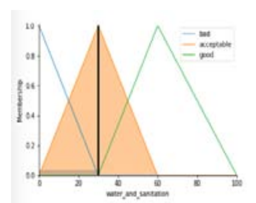
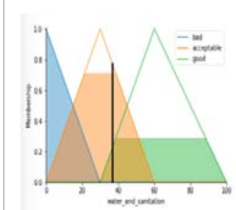
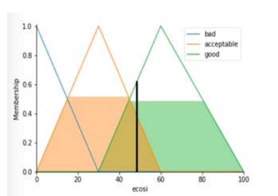
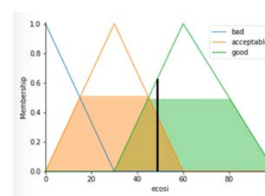
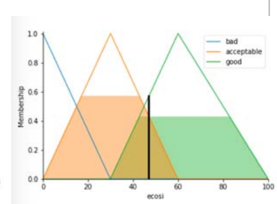
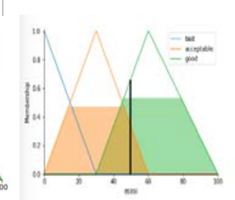
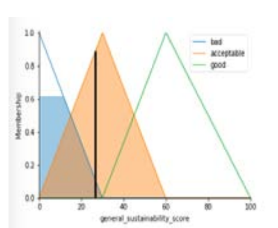
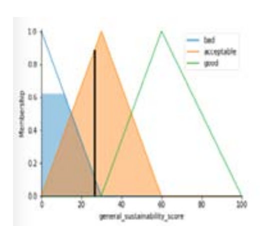
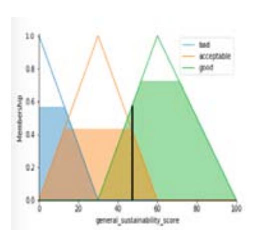
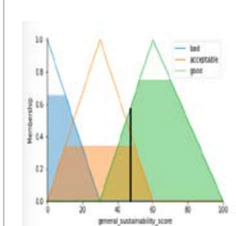
|---|---|---|---|---|---|
| 16 | Urban Planning |  |  |  |  |
| 17 | Wastewater |  |  |  |  |
| 18 | Water and Sanitation |  |  |  |  |
| 19 | ECOS1 |  |  |  |  |
| 20 | ECOSi Crisp Value | 48.4515 | 48.5864 | 47.0019 | 49.6479 |
| 21 | Global Score |  |  |  |  |
| 22 | Global Score Crisp Value | 26.4882 | 26.4584 | 47.1025 | 47.0857 |

*a) Table 5 Results Explanation*

In Table 5 (above) we have:

- City of Tbilisi (GEO) at column A
- City of Guadalajara (MEX) at column B
- City of Boston (USA) at column C
- City of London (UK) at column D
- Indicators are listed at the Table's lines.

Adapted SAFE Model Fuzzy result of Economy indicator(s) (for the four cities):

- Tbilisi has a numeric score of 27.2329, with a high membership degree at ACCEPTABLE, and a relatively high membership degree at BAD (Graph A1);
- Guadalajara has a numeric score of 54.2042, with a high membership degree at GOOD, and a medium membership degree at ACCEPTABLE (Graph B1);
- Boston has a numeric score of 33.0121, with a very high membership degree at ACCEPTABLE, and a very low membership degree at GOOD (Graph C1);
- London has a numeric score of 42.5339, with a high membership degree at ACCEPTABLE, and a medium membership degree at GOOD (Graph D1);

Adapted SAFE Model Fuzzy result of Education indicator(s) (for the four cities):

- Tbilisi has a numeric score of 39.0279, with a high membership degree at BAD, relatively high membership degree at ACCEPTABLE and a relatively low membership degree at GOOD (Graph A2);

- Guadalajara has a numeric score of 46.2247, with a high membership degree at ACCEPTABLE, and a medium membership degree at GOOD (Graph B2);
- Boston has a numeric score of 54.1088, with a very high membership degree at GOOD, and a medium membership degree at ACCEPTABLE (Graph C2);
- London has a numeric score of 50.8832, with a relatively high membership degree at GOOD, and a medium membership degree at ACCEPTABLE (Graph D2);

Adapted SAFE Model Fuzzy result of Finance indicator(s) (for the four cities):

- Tbilisi has a numeric score of 59.6755, with a very high membership degree at GOOD and a relatively low membership degree at ACCEPTABLE (Graph A3);
- Guadalajara has a numeric score of 13.0756, with a medium membership degree at BAD (Graph B3);
- Boston has a numeric score of 53.3368, with a high membership degree at GOOD, and a medium membership degree at ACCEPTABLE (Graph C3);
- London has a numeric score of 51.9278, with a high membership degree at GOOD, and a medium membership degree at ACCEPTABLE (Graph D3);

Adapted SAFE Model Fuzzy result of Governance indicator(s) (for the four cities):

- Tbilisi has a numeric score of 40.9456, with a very high membership degree at ACCEPTABLE and a low membership degree at BAD and GOOD (Graph A4);
- Guadalajara has a numeric score of 46.9240, with a very high membership degree at ACCEPTABLE and a high membership degree at GOOD (Graph B4);
- Boston has a numeric score of 47.7288, with a very high membership degree at ACCEPTABLE, and also a high membership degree at GOOD and a slightest membership degree at BAD (Graph C4);
- London has a numeric score of 40.4772, with a very high membership degree at ACCEPTABLE, and a low membership degree at GOOD (Graph D4);

Adapted SAFE Model Fuzzy result of Shelter indicator(s) (for the four cities):

- Tbilisi has a numeric score of 55.6007, with a very high membership degree at GOOD and a low membership degree at ACCEPTABLE (Graph A5);
- Guadalajara has a numeric score of 27.0628, with a high membership degree at ACCEPTABLE and a relatively high membership degree at BAD (Graph B5);
- Boston has a numeric score of 59.4777, with a high membership degree at GOOD, and a low membership degree at ACCEPTABLE (Graph C5);
- London has a numeric score of 60.6362, with a very high membership degree at GOOD, and a very low membership degree at ACCEPTABLE (Graph D5);

Adapted SAFE Model Fuzzy result of Health indicator(s) (for the four cities)

- Tbilisi has a numeric score of 39.3827, with a very high membership degree at BAD and a low membership degree at GOOD and an even lower membership degree at ACCEPTABLE (Graph A6);
- Guadalajara has a numeric score of 10.0341, with a very high membership degree at BAD (Graph B6);
- Boston has a numeric score of 37.6115, with a high membership degree at ACCEPTABLE, and a low membership degree at GOOD and BAD (Graph C6);
- London has a numeric score of 47.5721, with a very high membership degree at ACCEPTABLE, and a high membership degree at GOOD (Graph D6);

Adapted SAFE Model Fuzzy result of Safety indicator(s) (for the four cities):

- Tbilisi has a numeric score of 26.5344, with a high membership degree at ACCEPTABLE, and an almost as high membership degree at BAD (Graph A7);
- Guadalajara has a numeric score of 47.9997, with a very high membership degree at GOOD, an almost as high membership degree at ACCEPTABLE and a medium membership degree at BAD (Graph B7);
- Boston has a numeric score of 38.4643, with a high membership degree at BAD, an almost as high membership degree at ACCEPTABLE, and a medium membership degree at GOOD (Graph C7);
- London has a numeric score of 20.4454, with a very high membership degree at BAD, and a medium to low membership degree at ACCEPTABLE (Graph D7);

Adapted SAFE Model Fuzzy result of Telecommunication and Innovation indicator(s) (for the four cities)

- Tbilisi has a numeric score of 45.5658, with a very high membership degree at BAD and a high membership degree at GOOD (Graph A8);
- Guadalajara has a numeric score of 47.5484, with a very high membership degree at ACCEPTABLE, an almost as high membership degree at GOOD, and a low membership degree at BAD (Graph B8);
- Boston has a numeric score at 43.1992, with a high membership degree at BAD and a medium membership degree at GOOD (Graph C8);

- London has a numeric score of 45.3375, with a very high membership degree at BAD and a high membership degree at GOOD (Graph D8);

Adapted SAFE Model Fuzzy result of Transportation indicator(s) (for the four cities):

- Tbilisi has a numeric score of 47.5852, with a high membership degree at GOOD, an almost as high membership degree at ACCEPTABLE, and a medium membership degree at BAD (Graph A9);
- Guadalajara has a numeric score of 47.3632, with a very high membership degree at BAD, a very high membership degree at GOOD, and a low membership degree at ACCEPTABLE (Graph B9);
- Boston has a numeric score of 48.2151, with a very high membership degree at GOOD, a high membership degree at ACCEPTABLE, and a low to medium membership degree at BAD (Graph C9);
- London has a numeric score of 47.8583, with a very high membership degree at GOOD, a medium membership degree at ACCEPTABLE and at BAD (Graph D9);

Adapted SAFE Model Fuzzy result of HUMSi group of indicators (for the four cities):

- For Tbilisi, HUMSi has received a score of 29.9590, with a concentration of its membership degree at ACCEPTABLE, on a low level (Graph A10). It means the Human group of indicators has provided the information that they are in a level of acceptance, but still in a low condition.
- For Guadalajara, HUMSi has received a score of 29.9604, with a concentration of its membership degree at ACCEPTABLE on a low level (slightest bigger than Tbilisi) (Graph B10). It means the Human group of indicators has provided the information that they are in a level of acceptance, but still in a low condition.
- For Boston, HUMSi has received a score of 51.7908, with a concentration of its membership degree at ACCEPTABLE and GOOD, on a low to medium level (GOOD slightest bigger ACCEPTABLE) (Graph C10). It means the Human group of indicators has provided the information that they are in a level of acceptance but already evolved to a good position;
- For London, HUMSi has received a score of 52.4961, with a concentration of its membership degree at ACCEPTABLE and GOOD, on a medium to high level (GOOD bigger than ACCEPTABLE) (Graph D10). It means the adapted fuzzy calculi for the "human" group of indicators has provided the information that the city has acceptable characteristics, but already evolved very much to a good position;

Adapted SAFE Model Fuzzy result of Energy indicator(s) (for the four cities):

- Tbilisi has a numeric score of 27.0407, with a very high membership degree at ACCEPTABLE and a medium to high membership degree at BAD (Graph A12);
- Guadalajara has a numeric score of 26.1312, with a high membership degree at ACCEPTABLE and an almost as high membership degree at BAD (Graph B12);
- Boston has a numeric score of 26.0261, with a high membership degree at ACCEPTABLE and an almost as high membership degree at BAD (Graph C12);
- London has a numeric score of 15.6583, with a very high membership degree at BAD, and a very low membership degree at ACCEPTABLE (Graph D12);

Adapted SAFE Model Fuzzy result of Environment indicator(s) (for the four cities)

- Tbilisi has a numeric score of 44.4931, with a very high membership degree at BAD, a medium to high membership degree at GOOD, and a medium membership degree at ACCEPTABLE (Graph A13);
- Guadalajara has a numeric score of 44.6521, with a high membership degree at BAD, a medium to high membership degree at GOOD, and a medium membership degree at ACCEPTABLE (Graph B13);
- Boston has a numeric score of 42.8161, with a medium membership degree at BAD, a medium to high membership degree at ACCEPTABLE, and a medium membership degree at GOOD (Graph C13);
- London has a numeric score of 45.9163, with a medium to high membership degree at ACCEPTABLE, a medium membership degree at GOOD (Graph D13);

Adapted SAFE Model Fuzzy result of Fire and Emergency Response indicator(s) (for the four cities):

- Tbilisi has a numeric score of 47.4968, with a very high membership degree at BAD and a very high membership degree at GOOD (Graph A14);
- Guadalajara has a numeric score of 36.8213, with a high membership degree at BAD, a medium to high membership degree at GOOD, and a medium membership degree at ACCEPTABLE (Graph B14);
- Boston has a numeric score of 63.6628, with a medium membership degree at BAD, a medium to high membership degree at ACCEPTABLE, and a medium membership degree at GOOD (Graph C14);
- London has a numeric score of 63.3044, with a medium to high membership degree at ACCEPTABLE, a medium membership degree at GOOD (Graph D14);

Adapted SAFE Model Fuzzy result of Solid Waste indicator(s) (for the four cities):

- Tbilisi has a numeric score of 9.9686, with a very high membership degree at BAD only (Graph A15);
- Guadalajara has a numeric score of 21.6357, with a high membership degree at BAD and a medium membership degree at ACCEPTABLE (Graph B15);
- Boston has a numeric score of 28.6053, with a medium to high membership degree at ACCEPTABLE, and an almost medium membership degree at BAD (Graph C15);
- London has a numeric score of 31.7512, with a very high membership degree at ACCEPTABLE, a very low membership degree at GOOD (Graph D15);

Adapted SAFE Model Fuzzy result of Urban Planning indicator(s) (for the four cities):

- Tbilisi has a numeric score of 63.3363, with a high membership degree at GOOD only (Graph A16);
- Guadalajara has a numeric score of 18.9522, with a high membership degree at BAD and a low membership degree at ACCEPTABLE (Graph B16);
- Boston has a numeric score of 63.2986, with a very high membership degree at GOOD only (Graph C16);
- London has a numeric score of 63.3130, with a very high membership degree at GOOD only (Graph D16);

Adapted SAFE Model Fuzzy result of Wastewater indicator(s) (for the four cities

- Tbilisi has a numeric score of 9.9686, with a very high membership degree at BAD only (Graph A17);
- Guadalajara has a numeric score of 25.7874, with a medium to high membership degree at BAD and a medium membership degree at ACCEPTABLE (Graph B17);
- Boston has a numeric score of 64.7161, with a very high membership degree at GOOD (Graph C17);
- London has a numeric score of 64.7161, with a very high membership degree at GOOD (Graph D17);

Adapted SAFE Model Fuzzy result of Water and Sanitation indicator(s) (for the four cities):

- Tbilisi has a numeric score of 53.1570, with a high membership degree at GOOD and a medium membership degree at ACCEPTABLE (Graph A18);
- Guadalajara has a numeric score of 63.2986, with a very high membership degree at GOOD only (Graph B18);
- Boston has a numeric score of 29.9483, with a very high membership degree at ACCEPTABLE and a very low membership degree at BAD (Graph C18);
- London has a numeric score of 36.7871, with a very high membership degree at BAD, a high membership degree at ACCEPTABLE and a medium to low membership degree at GOOD (Graph D18);

Adapted SAFE Model Fuzzy result of **ECOSi** group of indicators (for the four cities):

- For Tbilisi, ECOSi has received a score of 48.4515 (A20), with a concentration of its membership degree at ACCEPTABLE and GOOD, on a medium to high level (Graph A19). It means the Ecological group of indicators has provided the information that they are in a level of acceptance, but already evolved to a good position.
- For Guadalajara, ECOSi has received a score of 48.5864 (B20), with a concentration of its membership degree at ACCEPTABLE and GOOD, on a medium to high level (Graph B19). It means the Ecological group of indicators has provided the information that they are in a level of acceptance, but already evolved to a good position.
- For Boston, ECOSi has received a score of 47.0019 (C20), with a concentration of its membership degree at ACCEPTABLE and GOOD, on a medium to high level (Graph C19) – ACCEPTABLE is greater than GOOD. It means the Ecological group of indicators has provided the information that they are in a level of acceptance, but already evolved to a good position.
- For London, ECOSi has received a score of 49.6479 (D20), with a concentration of its membership degree at ACCEPTABLE and GOOD, on a medium to high level (Graph D19) – GOOD is greater than ACCEPTABLE. It means the adapted fuzzy calculuscalculi for the "ecological" group of indicators has provided the information that the city has acceptable characteristics, but already evolved very much to a good position;

Adapted SAFE Model Fuzzy result of GENERAL SCORE (GE) (for the four 4 cities)

- For Tbilisi, GE has received a score of 26.4882 (A22), with a concentration of its membership degree at ACCEPTABLE (on a low to medium level), and with a relatively high membership degree at BAD (Graph A21). It means the city has an overall acceptable condition, but still has bad numbers regarding its ISO 37120 Standard indicators.
- For Guadalajara, GE has received a score of 26.4584 (B22), with a concentration of its membership degree at ACCEPTABLE (on a low to medium level), and with a relatively high membership degree at BAD (Graph B21). It means the city has an overall acceptable condition, but still has bad numbers regarding its ISO 37120 Standard indicators.
- For Boston, GE has received a score of 47.1025 (C22), with a high membership degree at GOOD, a medium membership degree at ACCEPTABLE, and a medium to high membership degree at BAD (Graph C21). It means the city has an overall good

condition with acceptable characteristics, but still has bad numbers regarding its ISO 37120 Standard indicators.

- For London, ECOSi has received a score of 47.0857 (D22), with a high membership degree at GOOD, a medium membership degree at ACCEPTABLE, and a medium to high membership degree at BAD (Graph D21). It means the city has an overall good condition with acceptable characteristics, but still has bad numbers regarding its ISO 37120 Standard indicators.

## IV. Discussion

Living organisms need food, water and oxygen to be converted in energy. This energy can then be used on things like walking, breathing, communicating and thinking. This process, however, creates residues that are disposed on the environment - this is a normal living organism metabolism synthesis (Science for Environment Policy, 2016). Following the same line of thought, cities also have their metabolism, i.e., they need water, raw material and processes to generate energy, providing the necessary means to its inhabitants and, at the end, generating residues too (Kennedy et al., 2007). Urban population will overpass 68% of total global population by 2050 (UN, 2014) what, together with the accelerating consume industry (to create economic development), can leverage the destruction of the environment, offering risks to economic activities and to the population health (Albino et al., 2015) – the balance between resources usage, energy generation and the posterior release of residues, is a very worrisome issue on this unbridled urban growth. Because of these issues, questions related to the way cities organize themselves have been taking place on discussions all over, trying to make them (the cities) more sustainable and more intelligent (Bulkeley and Betsill, 2005; European Commission, 2014; Giffinger and Haindl, 2007). Because of this, cities all around the globe are starting to show interest for sustainability, thinking of how develop themselves without surpassing biosphere regeneration's capacity (Carretero, 2002; Goodland and Daly, 1996; Hiremath et al., 2013; Holden et al., 2017).

The sustainability notion came through when risk to the environment has been noticed, because of the development a new social, economic and urban paradigm. The concept has become internationally spread out at the end of the 80's, followed by a wide adoption of strategies and speeches related to the theme (Elias and Krogstie, 2017). Since then, the most accepted idea of sustainable development is that "humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs" (WECD, 1987). However, this classical definition has been misinterpreted and misused, what made it receive a lot of critics. As a result, the sustainable development idea has become widely multifaceted, contested and many times has been interpreted as contradictory and oxymoronic (Hopwoodil et al., 2005; Jacobs, 1999; Jöst, 2002; Munda, 1997; Murcott, 1997; Redclift, 1987, 2005). The absence of a more universal definition for sustainable development has given origin to multiple interpretations and philosophical arguments, what inevitably lead to an explosion of social and economic indicators (Bibri and Krogstie, 2017).

Recently the discussion is taking another path: how sustainability can be reached with the help of "intelligence", that is, with technology and connectivity, bringing all urban systems together (Albino et al., 2017)? From new approaches of the city, information, initiatives and investments create actions towards the evolution of those urban systems, and as a way of controlling and measuring those incentives (and their results, of course), rankings have been created, being made of indicators that measured the performance of an object in a specific attribute (Meijering et al., 2014). Those rankings have exploded in quantity, with the objective of indicate best cities on each chapter (theme) and describe their strengths and weaknesses. Yet, as much alike as they can be, each one of the ranks carry an evaluation method, varying dimensions, indicators and weighs (for the indicators), what creates an unbalance between the ranked cities (Giffinger and Haindl, 2007).

Also, there isn't also a unique definition for "smart city" – only divergent points of view (and if you change the word smart for digital, for example, those points leverage). Regarding Albino (2015), the term intelligent city was firstly used on the 90's and had ICT (information and communication technology) as its main argument or requirement to consider a city "smart" – this vision, however, had been criticized for suggesting big investments on the information transmission, what has favored big players from the market. The concepts and definitions about smart cities have been evolving and gathering more space and dimensions to make cities more "circular", sustainable, popular and connected. An intelligent city incorporates infrastructure to facilitate mobility, adds effectivity on its main sectors, saves energy, improves and preserves air and water quality, identifies problems and fixes them promptly, besides so many other qualities. Those operations are always guided by interoperability between connected sectors and systems (Kanter and Litow, 2009).

A sustainable urban community should understand the connections between economy and environment – it should promote equity, social inclusion, be economically productive, have their buildings in

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harmony with nature, retain historical roots, and be preserved by all generations. On the other side, an unsustainable community uses all its resources faster than they can be renewed and generates more residues than the natural system can deal with (Rai, 2012). Regarding the sustainable intelligent cities, the evaluation of sustainability is widely used to support decision making processes on urban planning and development. Those processes need reliable tools and methodologies to show, evaluate and enhance the progress of their sustainability goals (Bibri and Krogstie, 2017), so multiple indicators to measure quality of life have appeared on the year 2000 (Mercer 2014). It is important to highlight again that the explosion of indicators came from the great of interpretations of 'sustainable development', and the different approaches for its operationalization. However, urban sustainability indicators were created by companies from the environment consultancy, capitalism, research and green citizenship organizations (Ahvenniemi et al., 2017; McManus, 2012). Thus, the tools of urban sustainability assessment were developed from a 'top-down' perspective by specialized organizations. However, several scholars (Berardi, 2013, Robinson and Cole, 2015, Turcu, 2013) advocate the integration of citizen-led, participatory and localized approaches. This is grounded in the underlying assumption that relationships among urban dwellers, their activities and the environment, should be better understood to achieve the level of sustainability required in terms of integrating their dimensions. The sustainability indicators should then be used by public administration and policy makers to confirm whether cities should implement development strategies, allowing the evaluation and monitoring of urban activities (Tanguay et al., 2010). Bottom line, evaluation performance tools are intended to classify sustainable cities or to enable cities to find best practices and compare best solutions (Ahvenniemi et al., 2017).

One of the challenges of building sustainable development is to create measurement instruments capable of providing information that facilitates the assessment of the degree of sustainability of societies, monitors the trends of their development and helps in the definition of improvement goals. Sustainability indicators have also been used as a way to improve the information based on the environment, to assist in the elaboration of public policies, to simplify studies and reports and to ensure comparability between different regions (Milanez and Teixeira, 2003). Working with sustainability indicators can help to seeing the links between different aspects of development within the various levels at which they coexist, and to appreciate the complex interaction between their various dimensions (OECD, 2006). Like any other management tool, the indicators have some technical limitations. Most indicators related to sustainability do not have a single conceptual system; they measure the approximation of reality, not reality precisely (Van Bellen, 2005). Also, inadequate selection of indicators leads to a deficient, often ambiguous, and therefore politically manipulating system or 'produced' or 'instituted' interpretations of reality. Therefore, before using them, it is recommended to point out the complementary aspect of the indicators: their reading and interpretation must be followed by a thorough analysis of the phenomenon in question (Kayano and Caldas, 2002).

ISO 37120 is part of a new series of international standards currently under development and "offers a holistic and integrated approach to sustainable development" (ISO, 2018), including indicators of municipal services, quality of life, smart cities and resilient cities, to provide a uniform approach. It helps cities learn from each other, allowing an uniform comparison across a broad range of performance measures, and supports policy development and prioritization. It is applicable to any city, municipality or local government that wants to measure its performance in a comparable and verifiable manner, regardless of size and location (ANSI, 2018). To help cities target and self-assess municipal service performance management and all service provision, ISO 37120 broadly describes 19 sectors and services provided by a city: economy, education, energy, environment, environment and climate change, finance, governance, health, housing, population and social conditions, recreation, safety, solid waste, sport and culture, telecommunications, transportation, urban/local agriculture and food security, urban planning, wastewater and water.

For each one of these, this standard provides an important indicator that should be reported by any user implementing the document. The standard also identifies a profile indicator for each, as well as a variety of support indicators. For example, for *economy*, the central indicator is the city's unemployment rate. The logic behind the determination is that the unemployment rate is considered one of the most informative indicators of the labor market and reflects the health of the economy as a whole. In this section, the standard describes how to accurately determine this primary indicator (ANSI, 2018). Maintaining, enhancing, and accelerating progress toward improved urban services and quality of life is also central to the definition of smart cities and resilient cities. ISO 37120 should be used in conjunction with two standards currently under development, ISO 37122 and ISO 37123, which will provide indicators to measure progress toward smart cities and resilient cities, respectively (ISO, 2018).

Considering that the different indicators are not homogeneous, it may be required to assign a weight to each indicator to allow aggregation. This assignment can be done through a combination of values that come from different judgments and different criteria, using a procedure based on "fuzzy logic" (Gagliardi et al., 2007). The daily natural language consists of being indefinite, with imprecise and polyvalent concepts, which can make approximate decision processes. The theory of fuzzy logic, or "fuzzy set theory", resembles human reasoning in the use of approximate information and uncertainty to generate decisions. It was specifically designed to mathematically represent uncertainty and imprecision and provide formalized tools to deal with the intrinsic imprecision for many problems (Smith, 1994). In this research, we try to attribute, through fuzzy logic, the weights for the different indicators that can be taken into account for intelligent and sustainable cities, thus obtaining a significant homogeneity and objectivity.

The proposed decision support model based on fuzzy logic provides meaningful solutions and suggestions for identifying strengths and weaknesses in specific aspects of intelligent city management. In addition, the model helps smart cities improve performance, through the analysis of the indicators movement. In summary, one of the key benefits of using this integrated framework as a decision support model, is that it serves as an effective, market-oriented effort that enables smart cities to improve performance and stand out in the fierce market competition.

There will still be questions to be answered, as which ISO 37120 indicators are critical to effectively measuring the sustainability of a system - and whether all the ideal indicators are really already there. Furthermore, which group of indicators is better suited to what level of development of a city (since developed cities can have their bad characteristics "masked" by some indicators with a high numerical level, that already possess the investment and care necessary for their maintenance). In any case, we understand that a global score, mainly comparing cities from the same country (sharing the same cultural, political and HDI reality), can help on defining the best way of investing towards a truly sustainable society.

*a) What is a Smart Sustainable City, after all?*

As per our understanding, the smart sustainable city concept goes far beyond than a simple modern city idea: it is a complex system where many forces interact to basically (1) receive inputs from the environment (water, air, land, temperature etc.), (2) treat those inputs in a way to generate energy and negative entropy to its inhabitants and to itself and (3) returns a treatable output to the environment (in a feasible way to permit the cycle to happen again). This system has many components, as shown in Figure 3 (that we have named "Sustainability Mandala"):

a) Public Management: the nucleus of the system, responsible for creating and maintaining all the subparts working together. It has to use its governance and inspection capacity to guarantee that all subjects in the system will collaborate to the negative entropy of it.
b) Society: co-responsible for auditing what the subjects of the system are doing, it has a sensitive role: to make changes start from each individual in the system, not only the organizations;
c) Private Companies: responsible for giving space to sustainable development, they have the main role to refrain from creating non-treatable outputs to the environment, acting responsibly and being accountable for their acts ('Public Management' and 'Society' are their main auditors, and all three components shall share feedback);
d) Indicators: a group of variables that receive numeric values and serve as the base to calculate the city general sustainability score (index) – through the adapted SAFE model. Creating ways to measure and keep those variables values updated is fundamental to control and foresee growth. The Sustainability Mandala is flexible enough to receive any kind of indicators – in this article and in Figure 4, we are using the ISO 37120:2017 group of indicators;
e) HUMSi: group of indicators that imply on the level of how the Human variables are being treated into the system;
f) ECOSi: group of indicators that imply on the level of how the Ecological variables are being treated into the system;
g) PDCA cycle (Plan, Do, Check and Act): the cycle to which all indicators are subject, at all times, through the effort of Private Companies, Government and Society. It is an effort to enhance the indicators numbers continuously;
h) Technology: the backbone that connects all the components of the system, it provides not only information workflow, but also all kinds of gadgets that will make the system work. It also connects indicators (and their subdivisions) managers and controllers, also making feedback a constant tool for system improvement.
i) Environment INPUTS: water, air, land, temperature;
j) City OUTPUTS: water, air, land, temperature, solid waste, wastewater, health.
k) Cities Interactions: Cities interact. Not only economically, but all kinds of output one city sends to another, can jeopardize the other city's state (like epidemics, solid waste, population and crime migration etc.). The interaction between neighbor cities shall be understood and seen very closely (and so do their effect over the other city indicators), and technology is a great ally on this subject.

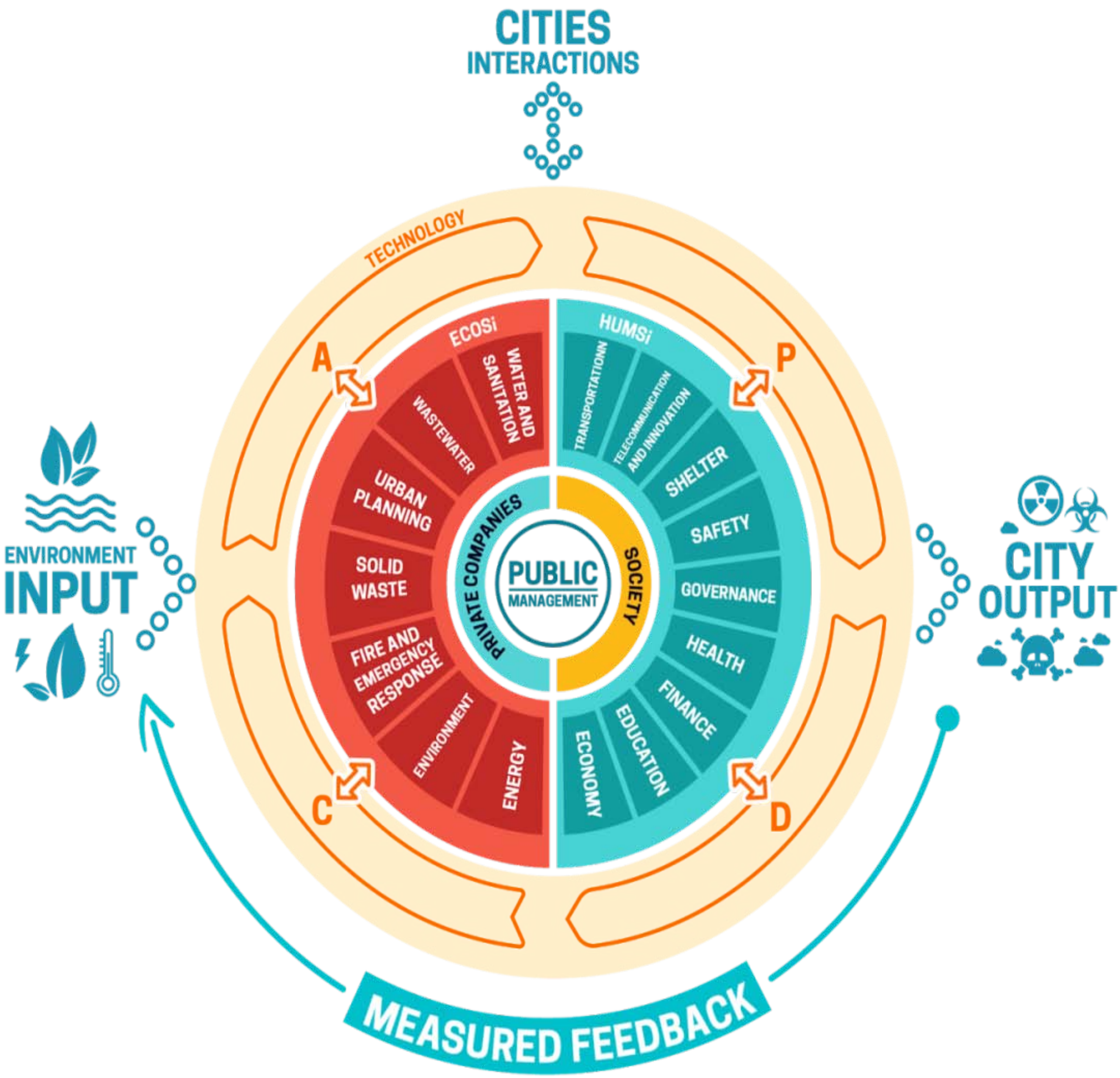


*Fig. 3:* Sustainability Mandala

The "sustainability mandala" represents a system (city) that is smart and sustainable at the same time. This system is closed in the sense that it can provide all the mechanisms to endurance and thrive in a competition environment, doing it in a sustainable way sustainably by controlling very closely the indicators indexes and their movement. With an implemented neural network, using all the technology wired throughout the system, we can have prediction models that will help decision makers perform better investments on the most responsive indicators – always aiming to enhance the general score. By doing so, the smart city will automatically provide better outputs to the environment (and to the other cities it interacts with), creating a positive chain reaction that will end up reflecting on itself, eventually. The city is the core of the sustainable development and being an example to others will make the first sustainable cities the smartest ones.

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# Susceptibilty Test for Road Construction: A Case Study of Shake Road, Irrua, Edo State

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*Abstract-* This research showed the significance of electrical resistivity method for road construction along Shake road, Irrua, Edo State, Nigeria. The aim of the study is to establish the near surface geological features that are predisposed to incessant case(s) of road failures few months or years after construction. The geophysical investigation involved three techniques; Vertical Electrical Sounding (VES), 2-D Electrical Resistivity Tomography (ERT) and Horizontal Profiling (HP) which covers a pilot test of 220 meters. Ten (10) VES were carried out using Schlumberger array with current electrode spacing varying from 1.00 to 100.00 m, with 2-D ERT using Dipole-Dipole electrode array with inter-station separation of 10 m and an expansion factor that varied from 1 to 5 and HP using Wenner array with an electrode spacing of 5 m interval. The VES interpretation results were used to determine the second order parameters for determination of integrity and susceptibility test of failure. The result obtained from the VES delineated three geoelectric units which Comprise of topsoil, clay layer, sand layer/shale horizon units. The 2 D imaging (Dipole-Dipole) gave information on the subsurface characteristic which indicates high, moderately high integrity and low integrity/a low competence material. The Wenner profile is characterised by low resistivity.

*Keywords: road, susceptibility test, dipole-dipole, geoelectric section, longitudinal conductance.*

*GJSFR-H Classification: FOR Code: 040499*

SUSCEPTIBILTYTESTFORROADCONSTRUCTIONACASESTUDYOFSHAKEROADIRRUAEDOSTATE

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# Susceptibilty Test for Road Construction: A Case Study of Shake Road, Irrua, Edo State

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*Abstract-* This research showed the significance of electrical resistivity method for road construction along Shake road, Irrua, Edo State, Nigeria. The aim of the study is to establish the near surface geological features that are predisposed to incessant case(s) of road failures few months or years after construction. The geophysical investigation involved three techniques; Vertical Electrical Sounding (VES), 2-D Electrical Resistivity Tomography (ERT) and Horizontal Profiling (HP) which covers a pilot test of 220 meters. Ten (10) VES were carried out using Schlumberger array with current electrode spacing varying from 1.00 to 100.00 m, with 2-D ERT using Dipole-Dipole electrode array with inter-station separation of 10 m and an expansion factor that varied from 1 to 5 and HP using Wenner array with an electrode spacing of 5 m interval. The VES interpretation results were used to determine the second order parameters for determination of integrity and susceptibility test of failure. The result obtained from the VES delineated three geoelectric units which Comprise of topsoil, clay layer, sand layer/shale horizon units. The 2 D imaging (Dipole-Dipole) gave information on the subsurface characteristic which indicates high, moderately high integrity and low integrity/a low competence material. The Wenner profile is characterised by low resistivity. The entire results correlate well with one another showing that all the techniques used was complemented. The result obtained from the pilot test of 220 m reveals that only 10% of the road survived susceptibility test, with a longitudinal conductance value of 1.099, and 30% of the class distribution were moderately susceptible to failure with longitudinal conductance values between 0.1000 to 0.999, while the rest of the study location with total longitudinal conductance values of 0.010 to 0.099, implying 60% susceptibility chance of failure.

*Keywords: road, susceptibility test, dipole-dipole, geoelectric section, longitudinal conductance.*

## I. Introduction

Nigeria as a country has suffered many consequences of incessant road failure leading to loss of life through preventable accidents and financial resources coming from Budgeting of road construction which may not last a year before remedial and rehabilitation work is required. This is a source of major concern not only for safety and sustainability of life but as well as saving Billions of Naira that is been wasted for sustaining and maintaining of roads after construction. There is no doubt that one of the major challenges facing Nigeria as a nation, is the sustainability of infrastructural developments which includes the road. The rate of failure of our road shortly after construction is very bothersome and a sizeable percentage of our annual National Budget is usually allocated for it. Indeed no nation can experience social and economic breakthrough without proper and adequate planning and utilisation of its scarce resource to develop infrastructural facilities including roads, in such a way that will achieve durability and sustainability to give room to the development of other sectors. Our experience has shown that most road that have been constructed within the last twenty to thirty years have not survived sustainable five years continuous integrity test without post construction/rehabilitation efforts, involving surface dressing, road cutting, and reinforcement, and many times total rehabilitation and reconstruction, when most often fail few years after such exercise (Ajayi, 1987). According to Akintorinwa, (2009), the statistics of failures of structures such as roads, buildings, dams, and bridges throughout the nation has increased geometrically. Although, road failure is an inevitable consequence of man's activities and a natural phenomenon as well (Ozegin, *et al.,* 2016), the usefulness of geophysical investigation in engineering sector of our economy cannot be overemphasised. Hence the application of geophysical imaging methods has been increasing in site characterisation (Ilugbo *et al.,* 2018) and geotechnical investigations throughout state and Federal high way departments. Geophysical methods have been used to assist in highway design construction repair and maintenance phases. Detailed knowledge of unforeseen, highly variable subsurface ground conditions reduces project risk and costs associated with "change of conditions" claims and improve construction and safety. Falowo, (2012), Yahya, 1989, Oladapo, 1997, Orange, 1997. Olorunfemi and Mesida, 1987; Olorunfemi, *et al.,* 2000. Therefore, this research work is to justify the need to carry out detailed pre-construction studies before any road construction work is embarked upon for safety, sustainability and economic survival of the country within Shake road, Irrua Area of Edo State.

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## II. Site description and Geology of the Study Area

The study was carried out at Shaka Momodu Road in Irrua, Esan Central Local Government Area of Edo State, Nigeria. It is bordered approximately by Latitude 6° 44' 21.56" N and Longitude 6° 13'8.45" E (Figure 1). It is underlain by the sedimentary rocks of the Anambra Basin, and geologic Formations are largely Imo Shale and Ogwashi-Asaba Formations although, there are some places in that area also underlain by the Bende-Ameki Formation. The climatic condition of Irrua and its environs fall within the warm-horrid tropical climate region where the wet and dry seasons are noticed prominently in the area. The dry season is between November and March while the rainy seasons are mostly between April and October. The average rainfall is between 1000 mm and 1500 mm with temperature as high as 36.7°. The elevation of the study area ranges from 343.9 m to 416.6 m above sea level. The predominant vegetation is moist deciduous forest, which is very rich in timber resources. The canopy is more open in the north than in the rain forest region which lies to the South with the tropical hard wood, timber such as iroko, obeche. Industrial and food crops found in the area include palm oil, rubber, cassava, yams, rice plantains, and many local important fruits strive within the forest.

## III. Methodology

The method that was used in this study is Electrical Resistivity using three techniques viz; Vertical Electrical Sounding (VES), 2-D Electrical Resistivity Tomography (ERT) and Horizontal Profiling (HP) with corresponding the configurations, Schlumberger, Dipole-Dipole and Wenner configurations respectively. Ten (10) sounding stations were occupied along the traverse, and the current electrode spacing (AB/2) was varied from 1 to 100 m. To process the electrical resistivity data, the apparent resistivity values were plotted against the electrode spread (AB/2). This was subsequently interpreted quantitatively using the partial curve matching method and computer-assisted 1-D forward modeling with WinResist 1.0 version software. The results from the VES interpretation was used to determined second order parameters such as the total transverse resistance (T) and the total longitudinal conductance (s). The dipole-dipole data were inverted using 2-D subsurface images using the DIPPRO™ 4.0 inversion software. The inter-electrode spacing of 5 m was adopted while inter-dipole expansion factor (n) was varied from 1 to 5. Resistivity values were obtained by taking readings using the Ohmega resistivity meter. The Wenner profiling was taken at 5 m interval and the data obtained was plotted on excel work sheet.

## IV. Results and Discussion

The results of the study were presented as Sounding curves, geo-electric sections, pseudo sections and graphs.

*a) Characteristic of the VES curves*

Curves types identified ranges from K, A, H and KH varying between three to four geo-electric layers. The KH curve type is predominating. Typical curve types in the area are as shown in Figure 2(a-d)

*b) Geoelectric and Lithological characteristic along the Traverse*

The geoelectric sections were represented by the 2-D view of the geoelectric parameters (depth and resistivity) derived from the inversion of the electrical resistivity sounding data. The geoelectric section along the Traverse (Figure 3) attempted to correlate the geoelectric sequence across the study area. The geoelectric sections identified three to four lithology units, comprising of topsoil, underlain by sandy shale/shaly sand, following by sand, and sand stones with layer thickness ranged from 0.5 to 5.2 m, 2.5 to 11.8 m, 6.9 to 16.9 m and beyond respectively.

*c) Dipole-dipole Pseudosection*

The 2-D Pseudosection was produced from the dipole-dipole data taken along the traverse (Figure 4). The Dipole-Dipole traverse covered a distance of about 220 meter along East to West Orientation. It delineated three to four major subsurface material/layer components, identified with various colour for easy characterisation; The layer lithological materials varies from Top soil mainly of sandy/fairly competent material as indicated in green/red colour with layer resistivity variation of 102.0 to 312.0 Ωm. Following this layer is another characterised by low resistivity variation from 15.6 to 459.0 Ωm. With the dominant resistivity being between 15.6 Ωm and 112.6 Ωm. These are as characterised by lithologic units that can be classified plastic shales, sandy shales, and shaly sands, with layer thickness varying from 1.10 to 16.50 m they are indicated with green, light green, and green/blue colour. These zones are characteristically weak and made up of attributes of low foundation integrity. The few zones with materials of high/moderate integrity can be found around the pegging of the traverse, at 70 to 80 m, and 200 to 220 m most often they occur at a depth not feasible for road construction purpose.

*d) Wenner Profiling*

Wenner profiling was produced from the Wenner data obtained along the traverse (Figure 5). The result obtained further revealed that the zone is generally weak with apparent resistivity varying from 48.60 to 200.00 Ωm from the beginning of the profile to 170 m while within 180 to 220 m demonstrated fear competence with apparent resistivity value ranging from 220 to 290 Ωm.

*e) Dar Zarrouk Parameters*

Result obtained from the VES interpretations were used to determine the second order parameters (Table 1). The estimation shows that the total longitudinal conductance varies from 0.010 –2.500 $\Omega^{-1}$ in the area with high total longitudinal conductance between distance of 140 to 170 m and low total longitudinal conductance at distance between 5 to 130 m (Figure 6). The qualitative use of this parameter is to demarcate changes in total thickness of low resistivity materials. The total transverse resistance ranges from 572 to 13614Ωm, which gives information both about the thickness and resistivity of the area. The result reveals that the lower the longitudinal conductance, the greater is the probability of the road to failure and vis-a-vis

## V. Synthesis of Results

Figure 7 displays the correlation of result obtained from the geophysical techniques. The Wenner profiling observed at a distance 170 to 220 m demonstrated fear competence with apparent resistivity value ranging from 220 to 290 Ωm which coincides with where the total longitudinal conductance is high at distance from 150 to 200 m. This also agrees with the high resistivity zone observed on the dipole-dipole pseudo-section at a distance 160 m and geo-electric section at a distance 180 to 200 m which indicate high integrity and low susceptibility to failure. The Wenner profiling zone is generally weak with apparent resistivity varying from 48.6 to 200.0 Ωm at a distance of 60 to 170 m correlate with where the total longitudinal conductance is low at distance between 5 to 140 m. These also agrees with the low resistivity zone observed on the dipole-dipole pseudo-section at distance between 80 to 120 m and the geoelectric section at distance 90 to 130 m which indicate low to moderate integrity and low to moderate susceptibility to failure. These results reveal that the techniques used for this study are complementary.

## VI. Determination of the Probability Integrity Test

The results obtained from total longitudinal conductance were used to determine the probability integrity test and susceptibility of failure (Table 2 and 3). Figure 8 reveals that only 10% of the road survived susceptibility test, with a longitudinal conductance value of 1.099, about 30% of the class distribution of the total longitudinal conductance test/susceptibility to failure, had a total longitudinal conductance value of between 0.1000 to 0.999 respectively 30% susceptibility to failure, while, the rest of the study location had a total longitudinal conductance value of 0.010 to 0.099, implying a 60% susceptibility chance of failure. Therefore using this as a basis for failure and predicting of index factor of ten Year. The probability that the road will fail within Ten Year when constructed is 90% and last Ten Years before any failure is 10%. The result shows that clay/shale is more predominant within the study location which is the major factor and a challenge responsible for 90% problem of road failures in Nigeria. The investigation illustrates that in recent times, the road cannot survive Ten years at stretch durability and stability, without one form of intervention program unless a proper precaution took place. So the need to construct our road with a minimum number of years as a guarantee before any failure can occur has never been of priority to our road builders. However, before construction of any road, there must be adequate studies of this nature

## VII. Conclusion

The study has revealled the significance of geophysical site study for highway construction design consideration. Geophysics, consequently, remains a very fundamental tool which can be applied in civil engineering work. The result obtained from VES delineated two to three geoelectric units which comprises of topsoil, clay layer, sand layer/weathered layer/shale horizon units. These results were used to determine the second order parameter which was used to delineate the integrity and susceptibility test of failure. All the results correlate well with one another showing that all the techniques used are complemented. No road can be constructed successfully in this area and most other part of the country with similar formation where clay or shale is a major factor without a thorough geophysical studies and information that will assist the construction Engineers; at using the right materials as well as excavating to a specific depth with a view to replacing the shale/clayey material, with necessary competent materials, complement with reinforcement and proper drainage. In addition to other geotechnical studies, no road can be constructed successfully without a good knowledge of the geology of that environment. Hence the inescapability of studies of nature before any construction work can be embarked on. The Government should insist on a guarantee of at least ten years, as part of contractual agreement with any road contractor and failure of which should be met with an appropriate sanction.

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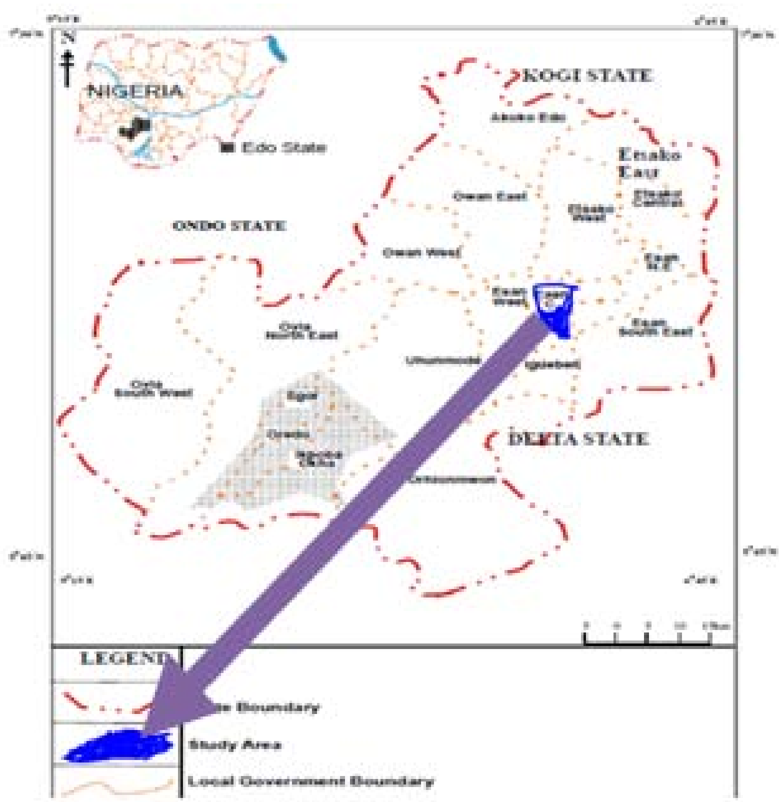



*Figure 1:* Map of Edo State Showing the Study Area (Ministry of Land and Survey, 2005.)

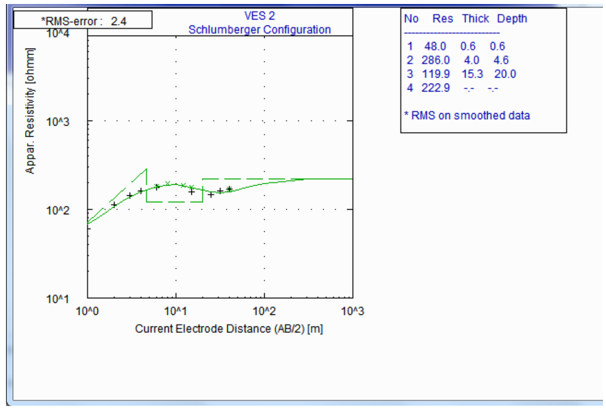



*Figure 2 a:* Typical Curve KH Type of the Study Area

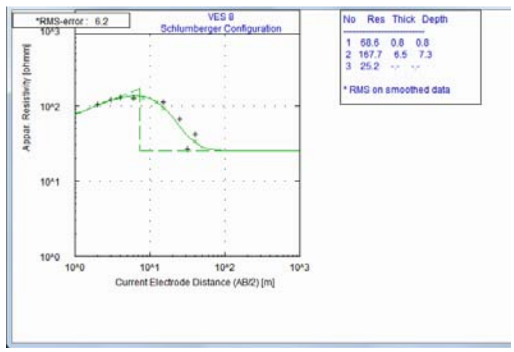



*Figure 2b;* Typical Curve K Type of the Study Area

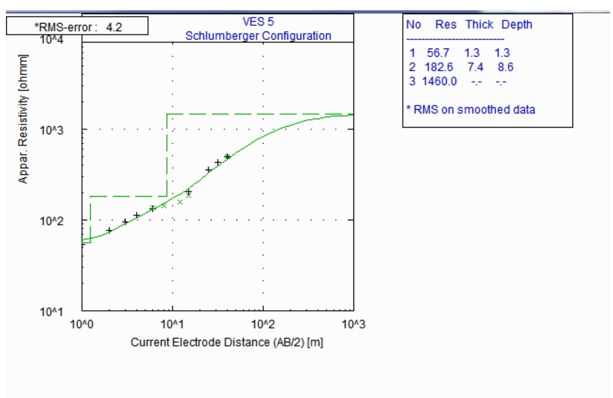
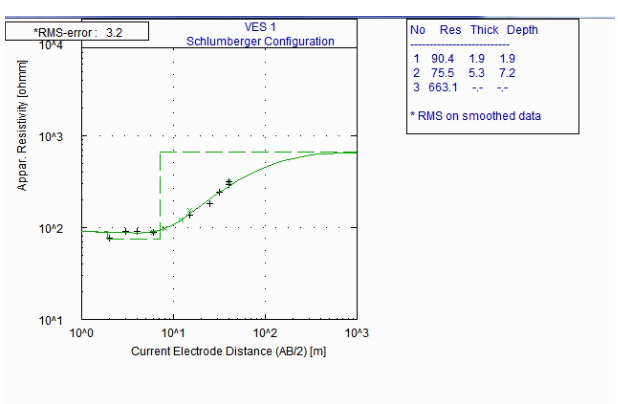



*Figure 2c;* Typical Curve A Type of the Study Area



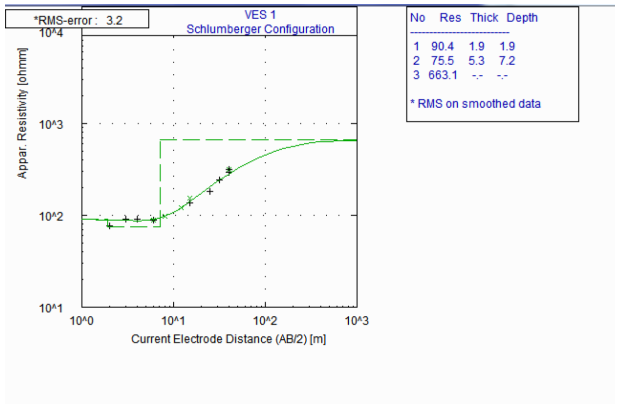



*Figure 2d:* Typical Curve H Type of the Study Area

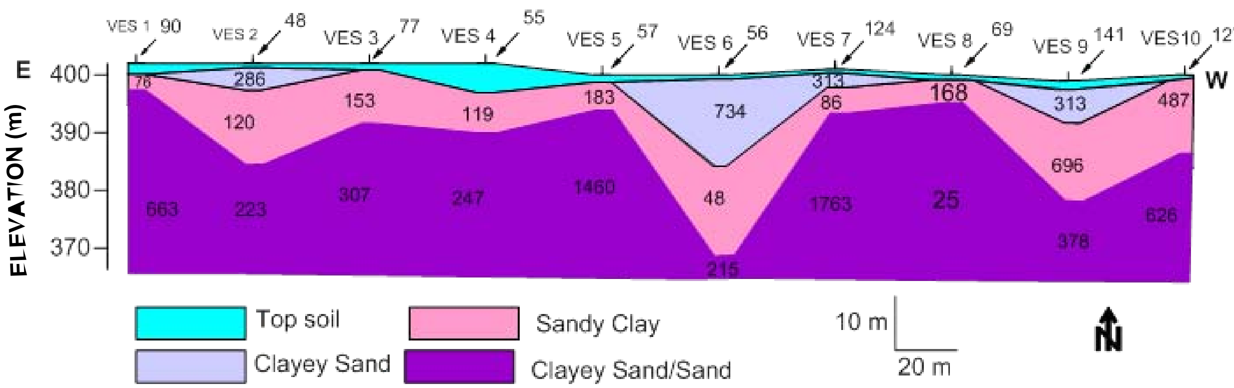
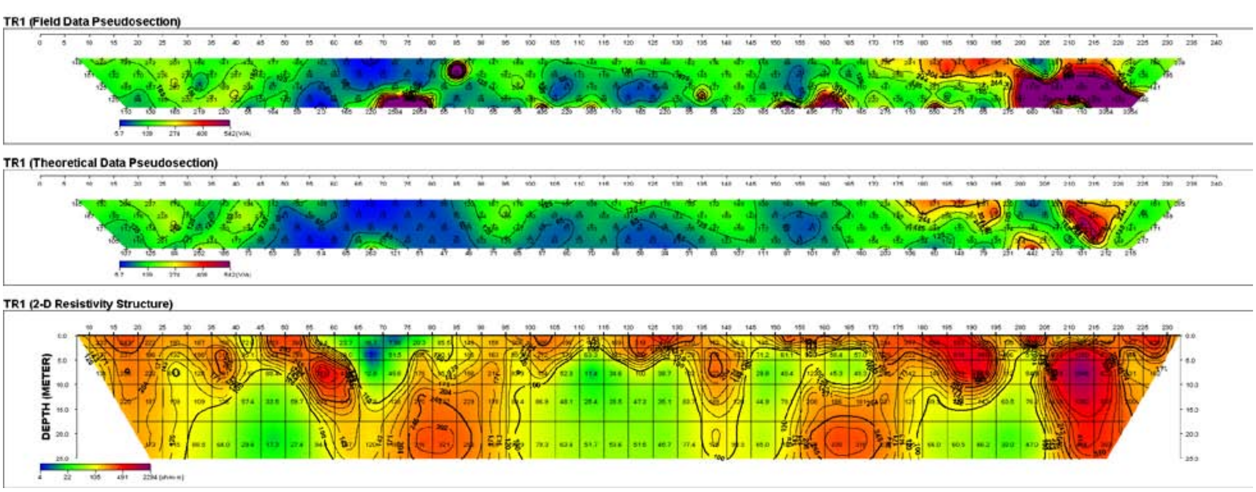



*Figure 3:* Geoelectric Section along the Traverse

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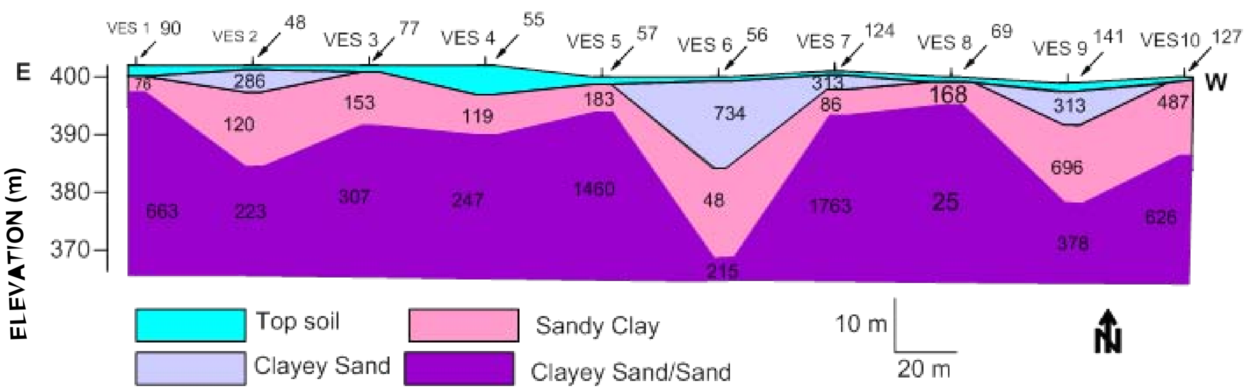


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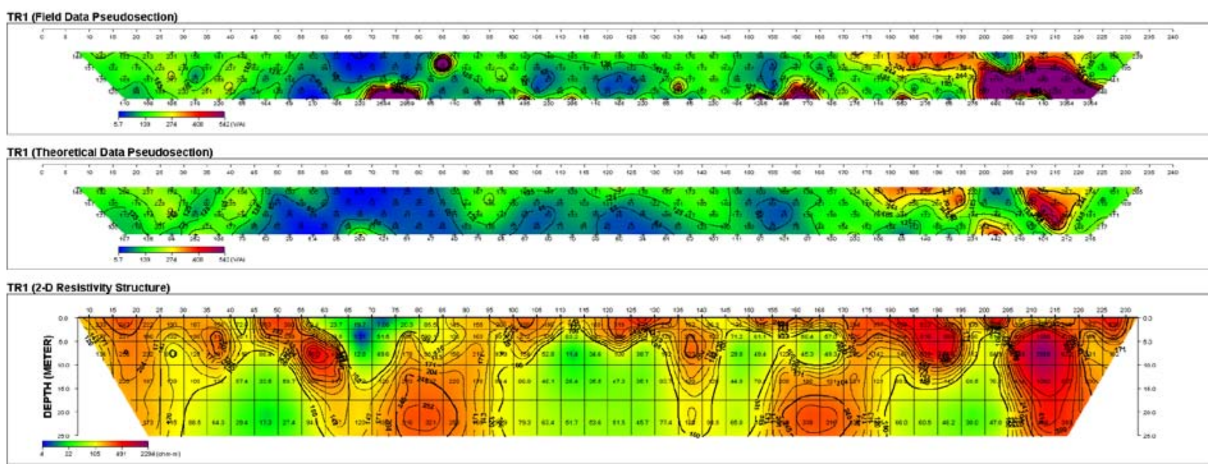


*Figure 4: Dipole – Dipole Horizontal Profiling along the traverse*

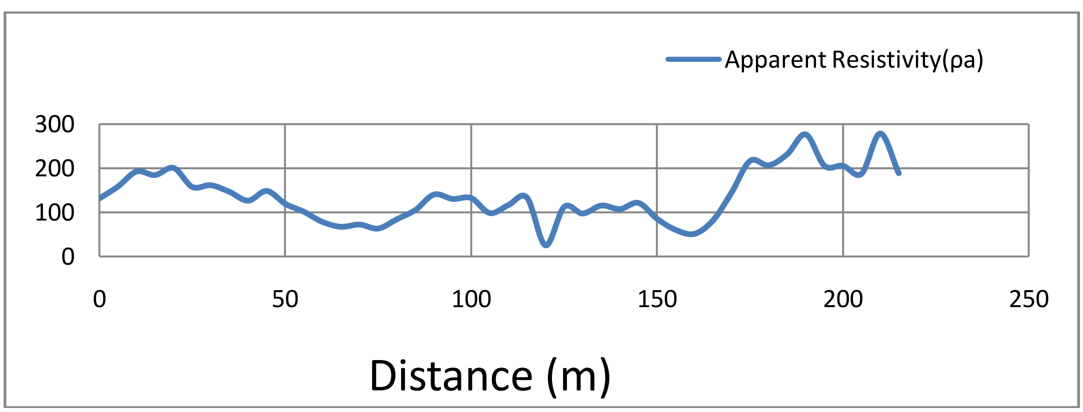


*Figure 5:* Wenner Profiling along the Traverse

*Table 2:* Dar Zarrouk Parameter of the Study Area

| | VES 1 | VES 2 | VES 3 | VES 4 | VES 5 | VES 6 | VES 7 | VES 8 | VES 9 | VES 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Total traverse resistance (T) | 572Ωm | 1474 Ωm | 1886 Ωm | 1412 Ωm | 1425 Ωm | 2759 Ωm | 461 Ωm | 1442 Ωm | 13614 Ωm | 2518.5 Ωm |
| Total Longitudinal conductance (S) | 0.091 | 0.155 | 0.092 | 0.174 | 0.064 | 0.273 | 0.095 | 1.099 | 0.051 | 0.075 |

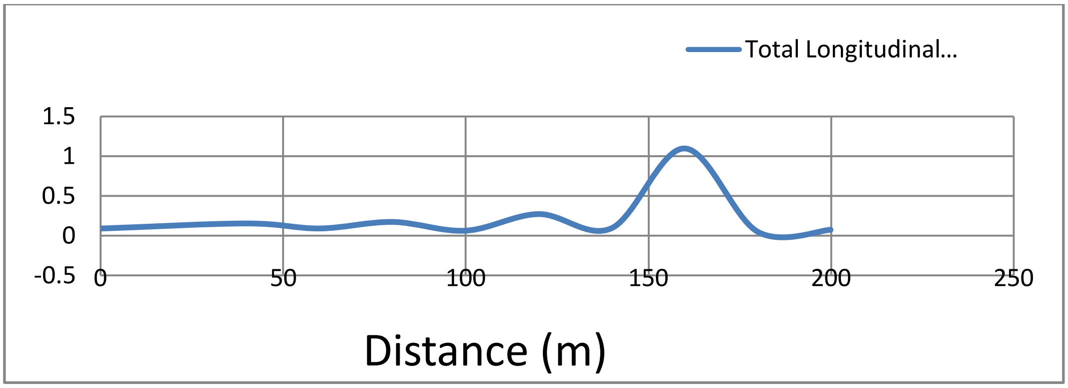


*Figure 6:* Total Longitudinal Conductance Profile of the Study Area

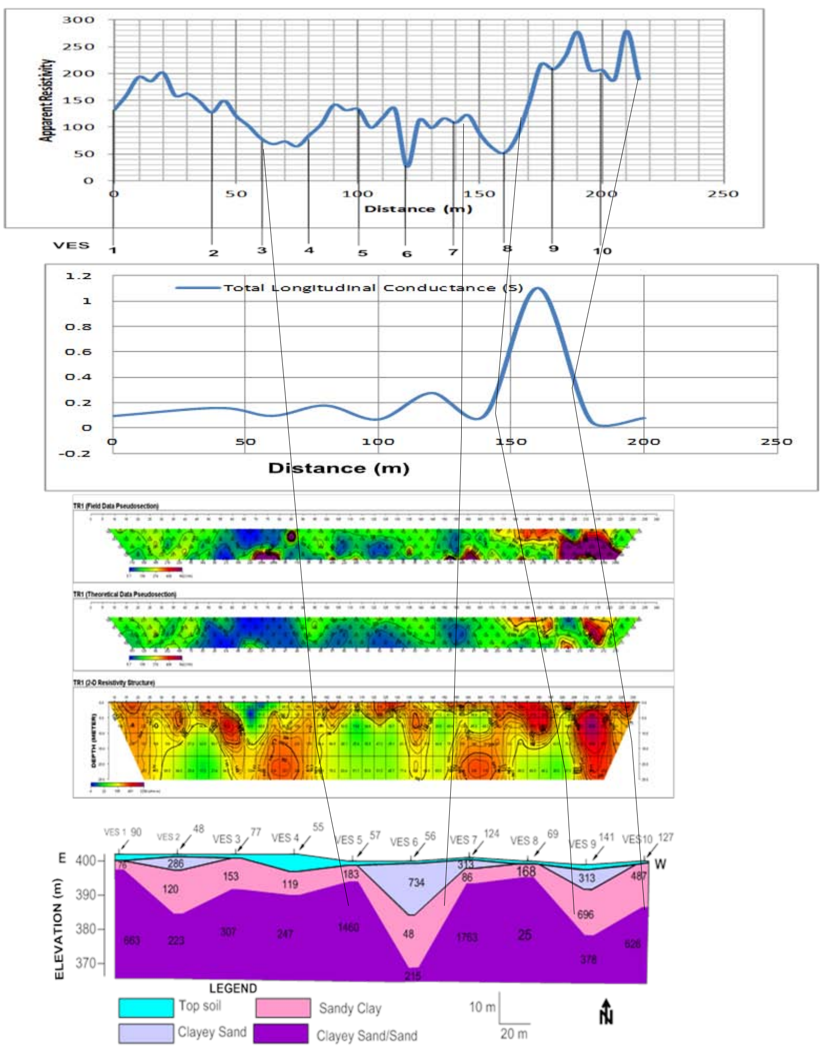


*Figure 7:* Showing the Correlation of Results

*Table 2:* Showing Longitudinal Range

| Longitudinal Conductance Range | Integrity Test | Susceptibility to Failure |
|---|---|---|
| 1.000 – 2.500 | High | Low |
| 0.100 – 0.999 | Medium/Moderate | Moderate |
| 0.010 – 0.099 | Low | High |

*Table 3:* Probability integrity test table / prediction of failure (in 10 years) before failure

| VES No | Total longitudinal conductant (S) | Class | Rating | Rating in % | Probability of failure/No of year before failure |
|---|---|---|---|---|---|
| 1 | 0.091 | 0.010 – 0.099 | Low integrity / High susceptibility to failure | 70% | Below 3 years |
| 2 | 0.155 | 0.1000 – 0.999 | Medium / Moderate integrity / Moderate susceptibility to failure | 20% | 8 Years and above |
| 3 | 0.092 | 0.010 – 0.099 | Low integrity/High susceptibility to failure | 70% | Below 3 years |
| 4 | 0.174 | 0.1000 – 0.999 | Medium / Moderate integrity / susceptibility to failure | 20% | 8 year and above |
| 5 | 0.064 | 0.010 – 0.099 | Low integrity / High susceptibility to failure | 70% | Below 3 years |
| 6 | 0.0274 | 0.010 – 0.099 | Low integrity / High susceptibility to failure | 70% | Below 3 years |
| 7 | 0.095 | 0.010 – 0.099 | Low integrity / High susceptibility to failure | 70% | Below 3 years |
| 8 | 1.099 | 1.000 – 2.500 | High integrity / Low susceptibility to failure | 10% | 9 years and above |
| 9 | 0.051 | 0.010 – 0.099 | Low integrity / High susceptibility to failure | 70% | Below 3 years |
| 10 | 0.075 | 0.010 – 0.099 | Low integrity / High susceptibility to failure | 70% | Below 3 years |

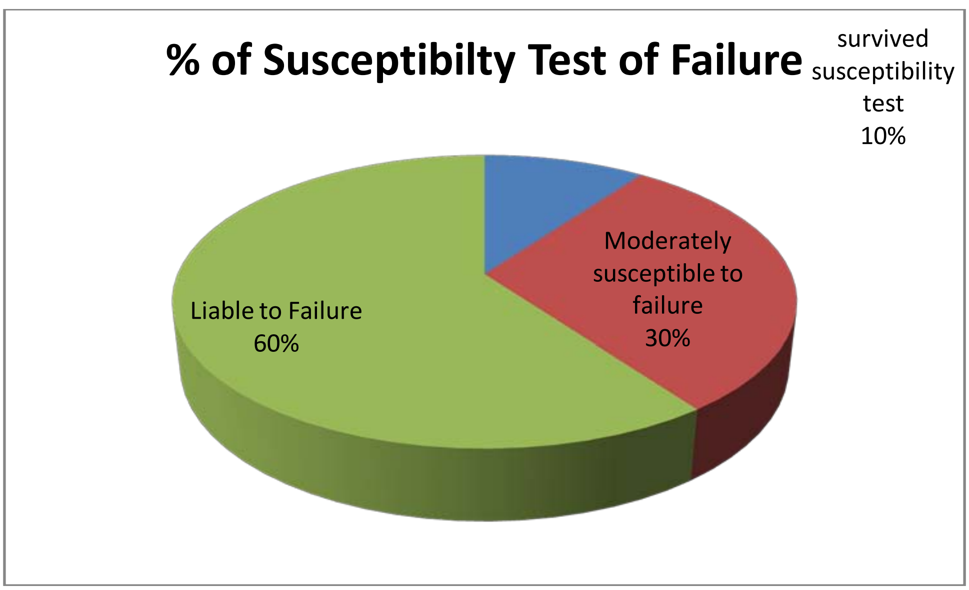


*Figure 8:* Show the Susceptibility Test of Failure

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# Use of Remote Sensing and Gamma Ray Spectrometric Data for Elucidating Radioactive Mineralized Zones, Wadi Jararah-Wadi Kharit Area, South Eastern Desert, Egypt

By Abdelmohsen G. Nady, Reda E. El Arafy, Mohammad G. Al-Ibiary, Maysa M. Nabeh & Samah S. Abdeen

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*Keywords:* *airborne gamma-ray spectrometry, landsat 8 operational land imager (OLI), hydrothermally altered rocks, argillic, phyllic, band ratios, principal component analysis (PCA).*

*GJSFR-H Classification:* *FOR Code: 040699*

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*Keywords: airborne gamma-ray spectrometry, landsat 8 operational land imager (OLI), hydrothermally altered rocks, argillic, phyllic, band ratios, principal component analysis (PCA).*

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## I. Introduction

Wadi Jararah-Wadi Kharit area is a part of the South Eastern Desert of Egypt (East Aswan area) and located between latitudes 23°00\` & 25°00\`N, and longitudes 33°00\` & 35°00\`E and occupies an area Approximately 38,000 Km2 (Fig.1). The area is characterized by a variety of igneous, metamorphic and sedimentary rocks ranging in age from Precambrian to the Quaternary ages.

Two types of remotely sensed data are used these are: Airborne Gamma-ray spectrometry & Landsat 8 (Operational Land Imager) OLI. Airborne gamma-ray spectrometry (AGRS) is a passive remote sensing technique that measures the naturally emitted gamma radiation emitted from three radioelements i.e., potassium, uranium ,and thorium, residing in soils and rocks located within the upper 30 cm of the earth's surface (Dickson, 2004; Chiozzi et al., 1998). The gamma-ray spectrometric measurements give quail-tative and quantitative determination of the individual radiation elements in the rocks and soils, and assist considerably in the search for uranium ores and therefore are of great importance to mineral exploration in general and geological i.e., lithological and structural mapping, in particular especially in regions where the geology is complicated, or the access is difficult. However, it must be note that it is a surface mapping method and cannot provide information about the underlying formations if their compositions are not reflect in the surface materials (Gharieb et al. 2004). In airborne gamma ray spectra, the photo peaks are the primary information about the geological and geophysical state of soil and rocks (Eugene, 2016). Darnley and Ford (1989) show that, in many situations, gamma-ray spectrometry is probably more useful than any other single airborne geophysical or remote sensing technique in providing information directly interpretable regarding surface geology. The interpretation of radioelement distribution requires a thorough under-standing of the rock types, vegetation, soil cover extent and alteration and enrichment processes

(Jayawardhana and Sheard, 1997). Due to the wide variation in the radioelements concentration in each rock type, no global classification is possible and this is the key in the geologic mapping.

On 4 February 2013, Landsat-8 was launched from Vandenberg Air Force Base in California. It is an American Earth observation satellite and the eighth satellite in the Landsat program. Landsat-8 joins Landsat-7 on-orbit, providing increased coverage of the Earth's surface. It is carrying a two-sensor payload, the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS). These two instruments collect image data for nine visible, near-infrared, shortwave infrared bands and two longwave thermal bands. They have a high signal to noise (SNR) radiometer performance, enabling 12-bit quantization of data allowing for more bits for better land-cover characterization. Landsat-8 provides moderate-resolution imagery, from 15 meters to 100 meters of Earth's surface and Polar Regions (A. Ariza, 2013). Landsat-8 data have been distributed to the general public on a nondiscriminatory basis at no cost to the user. The data can be easily downloaded from the (http://earthexplorer.usgs.gov) and (http://glovis.usgs.gov/) online linkages.

In the current study, the authors used the OLI image to map hydrothermal alteration zones in the study area. Hydrothermal alteration is defined as the reflection of a response of preexisting rock-forming minerals to physical and chemical conditions different than those, under which they originally formed, especially by the action of hydrothermal fluids (Arunachalam et al., 2014) with a possible temperature of 500˚C to 50˚C.

Previous studies explained the fact that certain minerals associated with hydrothermal processes, such as iron-bearing minerals (e.g., goethite, hematite, jarosite, and limonite) and hydroxyl-bearing or clay minerals (e.g., kaolinite and K-micas) show diagnostic spectral features that allow their remote identification.

Landsat 8 OLI data have been used by many authors for determining hydrothermal alteration areas e.g., (AB Pour & A Ali, 2014; M. Arunachalam et al., 2014; M. W. Mwaniki et al., 2015; AB Pour & M Hashim, 2015; F Masoumi et al, 2017; N Jain et al, 2018; H Aryanmehr et al, 2018; L Han et al, 2018).

This study aims at integrating airborne Gamma-ray spectrometry and OLI data for determining the tie relationship between airborne radioactive zones and different kind of alterations at areas which surveyed using the airborne and attempt to explore new radioactive zones that didn't survey using the airborne.

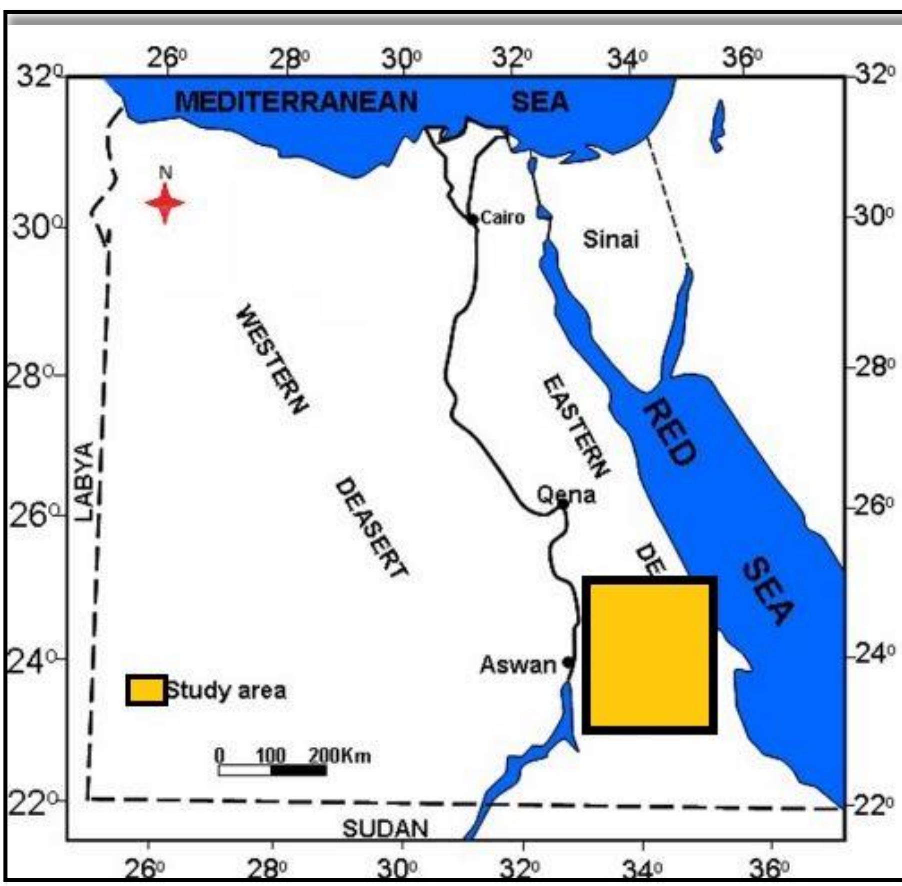


*Figure 1:* Location map of Wadi Jararah-Wadi Kharit area, South Eastern Desert, Egypt.

*a) Geologic setting*

The area of investigation is a part of the Pan African Arabian–Nubian Shield that was discussed by many workers. Topographically, the study area is mountainously characterized by moderate relief with high granitic hills generally extending several kilometers and form several peaks of relatively high elevation than the other rocks. Stratigraphically, it is comprises of foreland sediments (Nubian Sandstone Formation) represented by the Cretaceous and Tertiary Formations as well as Quaternary deposits filling wadis and their streams plus the enormous plains which located between high lands, these sedimentary rocks overlying Precambrian rocks. These varieties of rocks are exposing within a geological map of the area (Fig.2) (Conoco, 1987). Precambrian rocks cover the northeastern and southern parts of the study area and comprise a ring complex, meta-volcanic, meta-sediments, (meta-gabbro)-(meta-diorite) complex, ophiolites, gneisses, and calc-alkaline granites (older and younger). Upper Cretaceous volcanic (wadi Natash volcanic) and trachyte plugs cover the northeastern part of the area (Hashad et al., 1982). Meanwhile, the upper Cretaceous sedimentary rocks cover most of the southern parts and the northwestern parts of the study area, which are represented by the Abu Aggag, Timsah, Umm Barmil, Dakhla, Taref, Duwi, and Quseir Formations. Tertiary rocks represented by Pliocene Deposits which located as spots in the northwestern parts of the study area. In the southeastern and northeastern parts of the study area, leucocratic and melanocratic medium to high grade metamorphic rocks are observe. E. El Shazly & Kris, 1973 Indicated that, the area east Aswan is covered by well exposed basement-metamorphic rocks of Precambrian age, overlain with foreland sediments and volcanic, represented by Nubian sandstone and Wadi Natash volcanic of Cretaceous age. Structurally, the investigated area subjected to different tectonic movements giving rise to some complex structures and it dissected by various types of faults and joints, which are either concomitant with wadis (dry valleys) and drainage lines or cutting through country rocks (Fig.3).

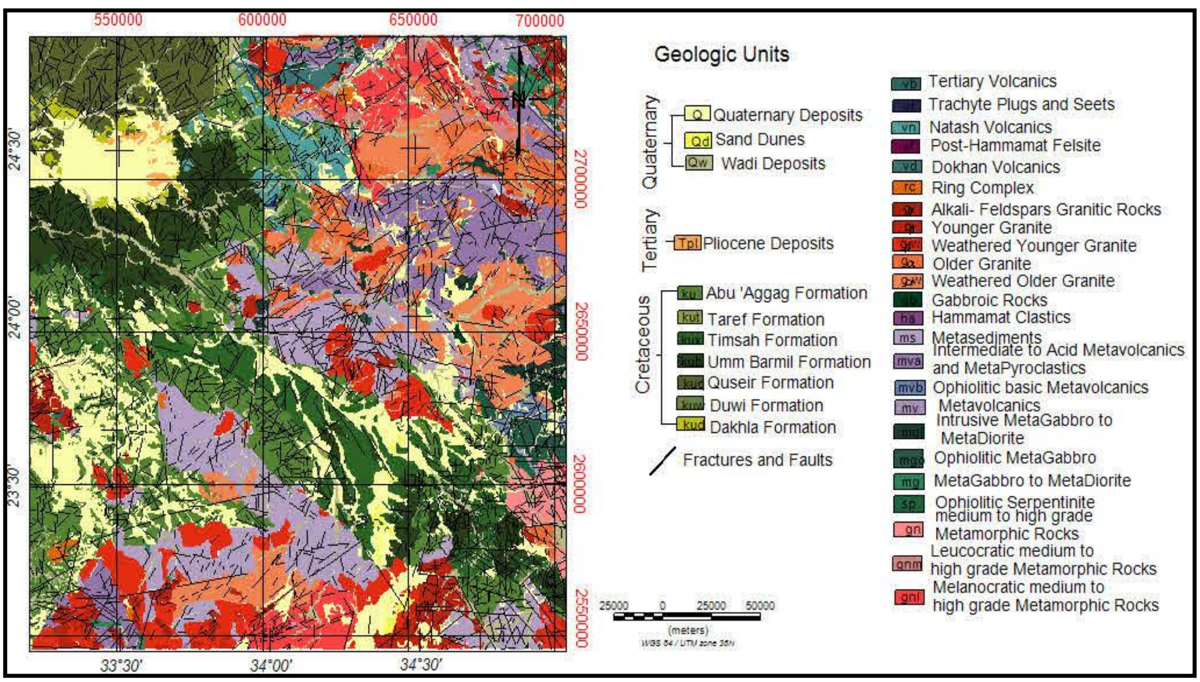


*Figure 2:* Geologic Map of Wadi Jararah-Wadi Kharit Area, South Eastern Desert, Egypt, (Conoco & EGPC, 1987).

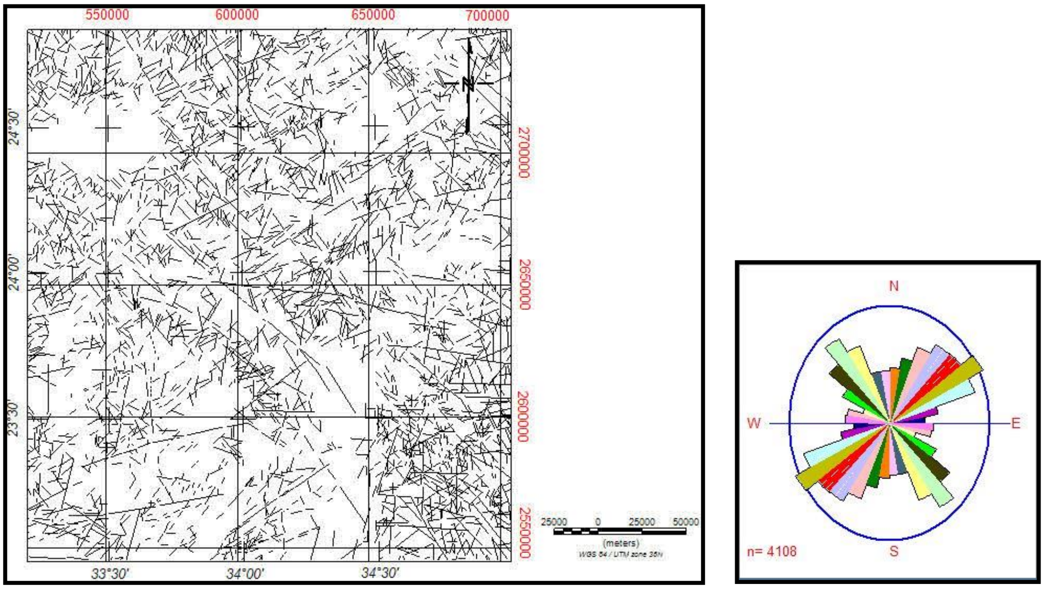


*Figure 3:* Main Structural Lineaments map and its Rose diagram extracted manually from (Conoco & EGPC, 1987).

These faults are extracted manually from (Conoco & EGPC, 1987) and mainly trend in the NE–SW, NW–SE, NNW-SSE, NNE-SSW, WNW–ESE, and ENE–WSW directions, as well as some minor faults trending in the N–S and E–W directions.

## II. Data and Methods

### a) *Airborne Radiometric data*

Wadi Jararah-Wadi Kharit area was included in the airborne gamma-ray spectrometric survey conducted by Aero Service Division, Western Geophysical Company of America, in 1984 over a large segment of the central and southern Eastern Desert, Egypt (Aero-Service 1984). The survey was flown along a set of parallel traverse flight lines oriented in an NE-SW direction, at 1.5 km spacing, while tie lines were flown NW-SE at 10 km intervals and 120-m terrain clearance. A high-sensitivity 256-channel airborne gamma-ray spectrometer was used to carry out the gamma-ray spectrometric survey (Aero-Service 1984). The obtained airborne gamma-ray spectrometric data were compiled and presented in the form of contoured maps of scale 1:50000.

### b) *Landsat-8 data*

The study area is covered by four cloud-free level 1T (terrain corrected) Landsat-8 images namely, LC81730432017109LGN00 (path/row 173/43), LC81730442017109LGN00 (path/row 173/44), LC81740432017116LGN00 (path/row 174/43) and LC81740442017116LGN00 (path/row 174/44) that downloaded from the US Geological Survey Earth Resources Observation and Science Center (http://earth explorer.usgs.gov) in TIFF format. Scenes (Path 173 Raw (43 and 44) and Path 174 Raw (43 and 44)) acquired on 19 and 26 April 2017, respectively, spatial resolution of approximate scene size 170 km north-south by 185 km east-west.

### c) *Data Analysis*

- *Preprocessing for aero-spectrometric data:* The collected gamma-ray measurements was: 1) corrected for background radiation resulting from cosmic rays and aircraft contamination, variations caused by changes in aircraft altitude relative to ground and Compton scattered gamma-rays in potassium and uranium energy windows, then compiled and finally displayed in the form of contour maps (Aero Service report, 1984). These maps show the apparent surface concentrations of radioelement Potassium (K in %), equivalent Uranium (eU in ppm), equivalent Thorium (eTh in ppm) and Total count Total counts were measured in count per second (cps) and then converted into micro Roentgen per hour (µR/h). 2) geo-referencing the map sheets for each element to UTM (Universal Traverse Mercator) system this process was necessary to achieve compatibility with Landsat 8 images and to ensure the coincidence between the different layers that could extracted from both types of data. 3) Gridding each element using minimum curvature tool. The preprocessing steps for aero-spectrometric data prepared using Oasis Montaj 8.3 package software.

The preprocessing and processing steps for aero-spectrometric data prepared using Oasis Montaj 8.3 package software and for Landsat-8 image using the ENVI (Environment for Visualizing Images) version 5.1 Software and Arc-GIS10.5 software package.

## III. Result and Discussion

### a) Airborne Spectrometry

#### i. Description of aero-spectrometric data

The aero-spectrometric images provide views of the overall patterns of elements and usually contain patterns related to various lithologies. The collected data involve the total count (TC), equivalent uranium (eU), equivalent thorium (eTh) and potassium concentration (K %) used to construct four image maps. Data values are multiplied by 10 to facilitate presentation and relative variation of the gamma radiation.

#### ii. Aero-spectrometric maps

- *TC map*

The TC map (Fig. 4) shows three radiometric levels, high, intermediate and low. The high level indicates values exceeding 60 µR/ h (from red to magenta). This level is observed over granitic rocks (especially younger granites), Duwi formation, Quseir formation Metamorphic rocks, Ring complex, and Natash volcanic. The intermediate level ranges from 40.4 to 60 µR/ h (from green to yellow) and is associated mainly with Cretaceous formations (Um Barmil, Timsah, Abu Aggag, Taref, and small parts in Quseir formations) and small parts in Meta-sediments, Meta-volcanic, Meta-gabbro, undifferentiated Quaternary deposits, Pliocene deposits, and Wadi deposits. The low level is less than 40.4 µR/ h (from deep blue to green) and extends over Undifferentiated Quaternary deposits, Dakhla formation, Wadi deposits, Abu Aggag Formation, and small parts in Timsah formation, Um Barmil formation, Meta-sediments, older granite, and Meta-volcanic.

- *eU map*

The eU map (Fig. 5) can be classified into three levels; the first level expands up to 30.6 ppm (from red to magenta) and is associated with younger granites, ring complex, Duwi Fm, Quseir Fm, Um Barmil Fm, and Timsah Fm. The intermediate level ranges from 10 to 17 ppm (from green to yellow) and is associated mainly with undifferentiated Quaternary deposits, older granites with small parts in Meta-sediments, Meta-volcanic, Timsah Fm, Um Barmil Fm, Quseir Fm, Abu Aggag Fm, and Metamorphic rocks. The low levels with values less than 10 ppm extend over metasediments, Abu Aggag formation, Um Barmil formation, Metavolcanics with small parts in older granites, undifferentiated meta-morphic rocks, and meta-gabbro.

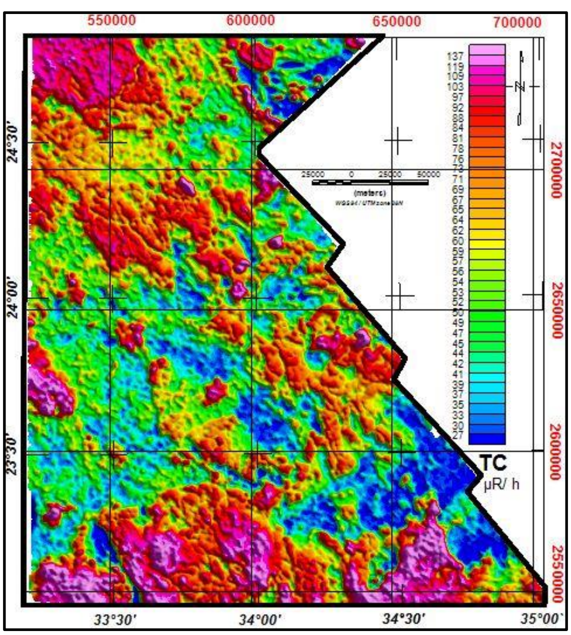


*Figure 4:* Colored image map of TC in µR/ h of Wadi Jararah-Wadi Kharit area, South Eastern Desert, Egypt. (Data value * 10).

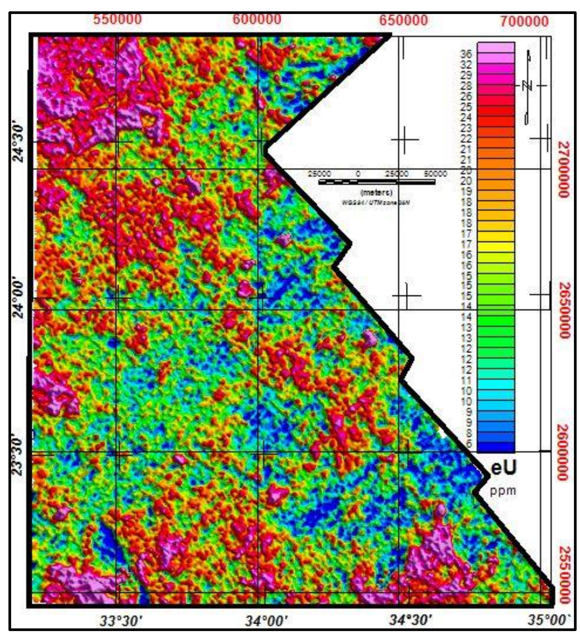


*Figure 5:* Colored image map of eU in ppm of Wadi Jararah-Wadi Kharit area, South Eastern Desert, Egypt. (Data value * 10).

- *eTh map*

The eTh map (Fig. 6) can be divided into three levels. The first level increases up to 108 ppm and is associated with younger granites, ring complexes, Duwi Fm, Quseir Fm with small parts in Um Barmil Fm, Timsah Fm, Metamorphic rocks, and Natash volcanic. The second level ranges from 37 to 58 ppm and is restricted over the undifferentiated Quaternary deposits, Wadi deposits, Abu Aggag Fm, meta-sediments, Dakhla Fm, Pliocene deposits, Meta-volcanic, Older granites

Fm, Pliocene deposits, Meta-volcanic, Older granites with small parts in Um Barmil Fm, Timsah Fm, Metamorphic rocks, and Quseir Fm. The low level decreases to less than 37 ppm, which is mostly associated with Abu Aggag Fm, Um Barmil Fm, Meta-sediments, Meta-volcanic, Meta-gabbro, and some older granite.

- *K% map*

The K map (Fig. 7) It indicates that Abu Aggag formation and Um Barmil formation with small parts in Taref formation, Quseir formation, and undifferentiated Quaternary deposits represent the low level (less than 3 %); while the intermediate level ranges from 3 to 10 %, which is connected with Quseir formation, Timsah formation, Um Barmil formation, Meta-sediments, Meta-volcanic with some parts in Abu Aggag formation, and Wadi deposits. The high level (up to 28 %) is associated with younger granites, metamorphic rocks, ring complex, meta-sediments, and meta-volcanic.

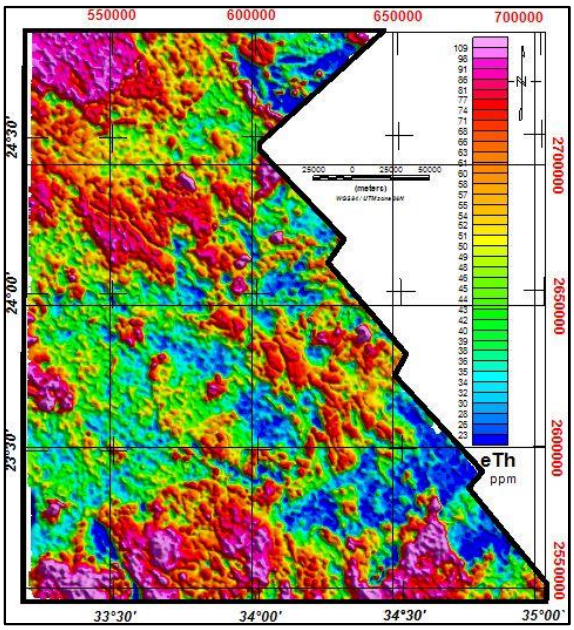


*Figure 6:* Colored Image Map of Eth In Ppm of Wadi Jararah-Wadi Kharit Area, South Eastern Desert, Egypt. (Data Value * 10).

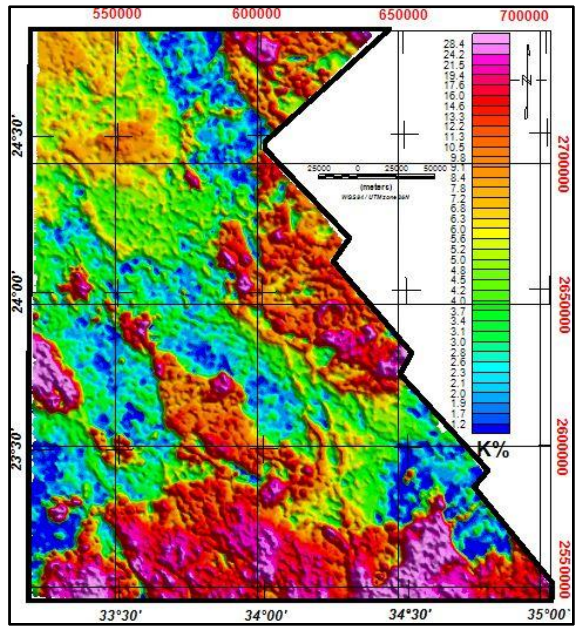


*Figure 7:* Colored Image Map of K% of Wadi Jararah-Wadi Kharit Area, South Eastern Desert, Egypt. (Data Value * 10).

b) *Ternary (Composite) Images*

Ternary maps are color composite images generated by modulating the red, green and blue in proportion to the radioelement concentration values of the K, eTh, eU and their ratio grids. Since particular rock types often have distinctive ratios of the three radioactive elements, the ternary maps of these ratios are a useful geological and mineral exploration tool for discriminating the zones of consistent lithology and contacts between contrasting lithologies (Duval 1983). Four composite color image maps were prepared as follows:

1. Radioelements composite image map K, eTh and eU (Fig.8).
2. Equivalent uranium composite image map eU, eU/eTh and eU/K (Fig.9).
3. Equivalent thorium composite image map eTh, eTh/eU and eTh/K (Fig.10).
4. Potassium composite image map K, K/eTh, K/eU (Fig.11).

- *Radioelement composite image map*

Different rock types have different characteristic concentrations of radioelements, potassium, uranium and thorium. Therefore, concentrations calculated from gamma-ray spectrometric data can be used to identify zones of consistent lithology and contacts between constraining lithologies. The three radioelements composite image map (Fig.8) of the study area shows the variations occurring in the three radioelements concentrations, which mainly reflect lithologic variations. This map is a three-element display of equivalent uranium (ppm), equivalent thorium (ppm) and potassium (%). The colors at each point inside the triangle represent different ratios of the radioelements, according to the color differences on the absolute three radioelements composite image map. The eU, eTh and K% images emphasize the radioelement and high light areas, where the particular radioelement has relatively higher concentrations.

It was noticed that the higher light zones are correlated with granite rocks, Ring complexes, and metamorphic rocks, which are normally characterized by their strong radio-spectrometric responses and elemental differences. The characteristic radioelement ratios are visible on the ternary radioelements map (Fig.8). Consequently, they can be easily discriminated from the surrounding rock units with spatial correlation to zones of anomalously high K, eU and eTh levels (areas in white color) are illustrates as yellow polygons (Fig.8), as occurred in the Southern (like G. Abu Maru, G. Hadayid, G. Uqab El Nugum), Central (like Sikhat Al Jallabah, Rawad El Kabsh, Khushaybat Umm Safi, G. Dihmit, G. Abu Gihan, G. Ghurab Al Atshan, G. Ghurab Ar Rayan, Homor Akarim, and G. Nikeiba) and Eastern part of Northeastern portions (like Urf Abu Hamam) of the study area. These high radioactive zones (bright or white zones) are illustrated in Table 1. The blue polygon in refers to the highest uranium concentrations which associated with Duwi (phosphate) formation.

Meanwhile, the ternary (three radioelements) composite image map shows black areas of weak radioelement contents as indicative to the low radioactive rocks as Abu Aggag Fm, Um Barmil Fm, Meta-volcanic with some Meta-sediments and Meta-gabbro. These dark zones are recorded at most of the Southern (like W. el Quffa, G. Hareigal, Qarn el Ties, G. Abu Hashim, G. Tarbtie, G. Abraq, and G. Kalat) parts of the study area as well as small parts in the Northeastern portions (like W. Beizih and W. Sha'it).

*Table 1:* Summary of Radioactive Zones of the study area

| No. | Name of Radioactive Zone | Rock Type | Situation |
|---|---|---|---|
| A | G.Abu Marw | Younger Granite | SW |
| B | G.Uqab El Nugum | Younger Granite | SE |
| C | G. Umm Naqa | Ring Complex | SW |
| D | G. Ghadir_ib | Younger Granite | S Central |
| E | G.Dihmit | Younger Granite | SW |
| F | Sikhat Al Jallabah | Younger Granite | SW |
| G | Rawad El Kabsh | Ring Complex | SW |
| H | Khushaybat Umm Safi | Younger Granite | S Central |
| I | G.Nikeiba | Younger Granite | SE |
| J | G. Ghurab Al Atshan | Younger Granite | NE |
| K | G. Ghurab Ar Rayan | Younger Granite | NE |
| L | Homor Akarim | Younger Granite | NE |
| M | G.Abu Gihan | Younger Granite | NE |
| N | Urf Abu Hamam area | Younger Granite | NE |
| O | Natash Volcanics | Natash Volcanics | NE |

- *eU Composite image map*

The uranium composite image (Fig.9) combines eU (in red) with the ratios of eU/eTh (in green) and eU/K (in blue). The relative concentration of uranium concerning both potassium and thorium is an important diagnostic factor in the recognition of the possible uranium deposits (IAEA, 1988). The uranium composite image also reflects lithological differences and could be useful in geologic mapping problems (Duval, 1983). Therefore; this map could assist in identifying the anomalous zones (bright areas on the image) of the enriched uranium concentration.

It was noticed that the high Uranium concentration (bright color) in eU, eU/eTh and eU/K ternary map are spatially correlated with Dakhla Fm, Duwi Fm, younger granites, Ring complexes and some dispersed spots in Wadi deposits. The dark areas (low uranium values) are mainly associated with the meta-sediments, Meta-volcanic, meta-gabbro with small parts in undifferentiated Quaternary deposits and older granites.

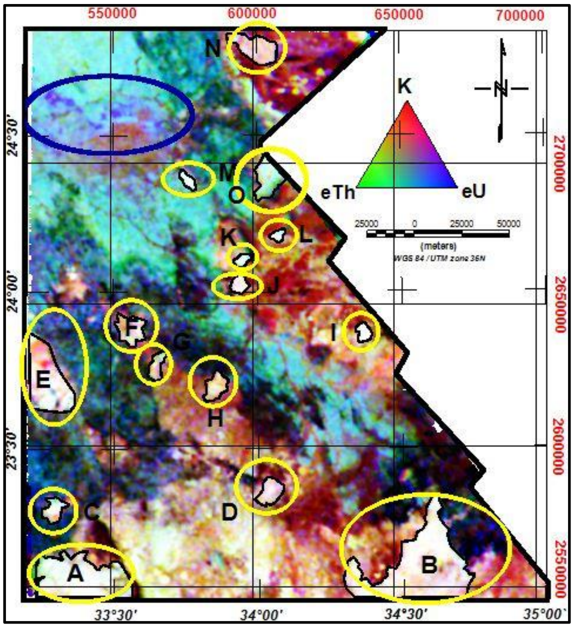

*Figure 8:* False colored Radioelements Ternary image of Wadi Jararah-Wadi Kharit area, South Eastern Desert, Egypt.

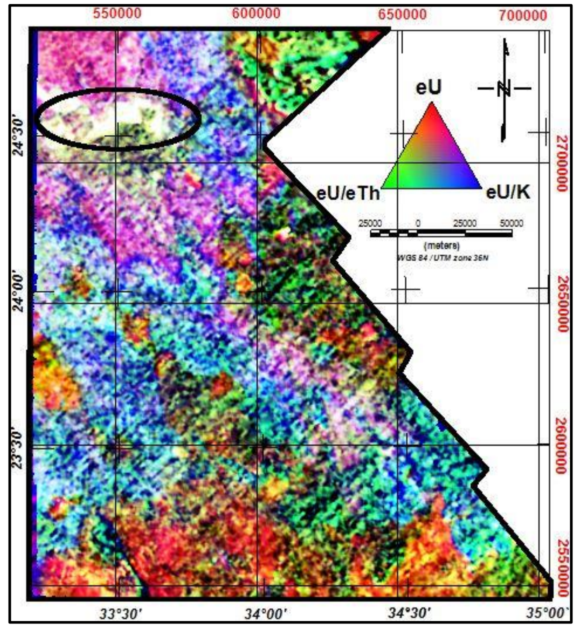

*Figure 9:* False colored Equivalent Uranium Ternary Image of Wadi Jararah-Wadi Kharit area, South Eastern Desert, Egypt.

- *eTh Ternary Image*

The thorium composite image (Fig.10) combines eTh (in red), eTh/eU (in green) and eTh/K (in blue). This image emphasizes the relative distribution of thorium and highlights areas of thorium enrichment. The blue and pale blue color on this image is a good pointer to parts of Abu Aggag Fm, Wadi deposits, undifferentiated Quaternary deposits, Taref Fm and small parts in Um Barmil Fm, which indicates that these areas are having high eTh/K concentrations. The pale magenta color is associated with Timsah Fm, Um Barmil Fm, and Quseir Fm, which indicates that these areas are having high eTh and eTh/K concentration. The pale green color is mainly related to meta-sediments with some older granite and undifferentiated Quaternary deposits, which indicates that these areas are having high eTh/eU concentrations. The pale red and the yellowish red color is mainly associated with younger granite and ring complexes, which means that these areas are having high eTh and eTh/eU concentrations. It was noted that the dark parts (low relative thorium values) are mainly associated with the Meta-volcanic, older granites with some parts in meta-sediments. There are some dispersed bright spots in the central part of the study area trending NW-SE and associated with Wadi deposits with some parts in Um Barmil, Timsah, and Quseir Formations.

- *K Ternary Image*

The potassium composite image map (Fig.11) combines K (in red) with K/eTh (in green) and K/eU (in blue). This image shows the overall spatial distribution of relative potassium concentrations. The bright zones (high values) are well correlated with the younger granites, ring complex, metamorphic rocks, and metasediments, which recorded at the southern, central and central part of the Eastern parts of the study area as well as some spots in the Northeastern and Western parts. The Pale blue color is mainly associated with Meta-sediments, Meta-volcanic, some older granite, and Um Barmil Fm, which means that these areas are having high K/eTh and K/eU concentrations. The dark zones on this image (low relative potassium values) are associated with Abu Aggag, Timsah, Taref, and Um Barmil Formations and located at most of the rest of the study area.

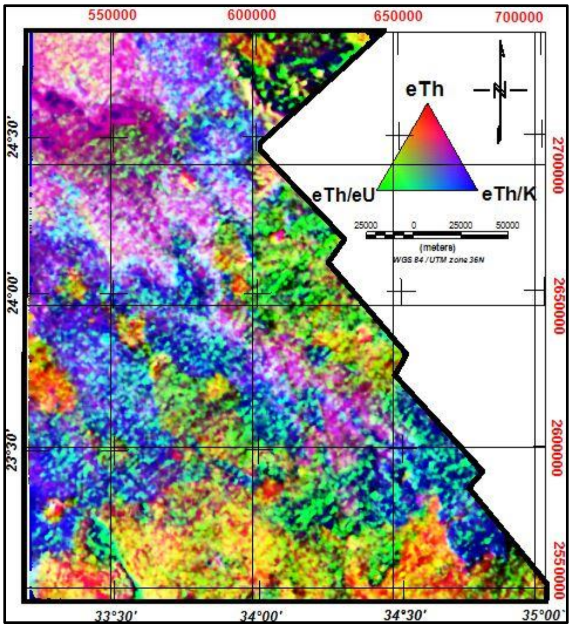


*Figure 10:* False colored Equivalent Thorium Ternary Image of Wadi Jararah-Wadi Kharit area, South Eastern Desert, Egypt.

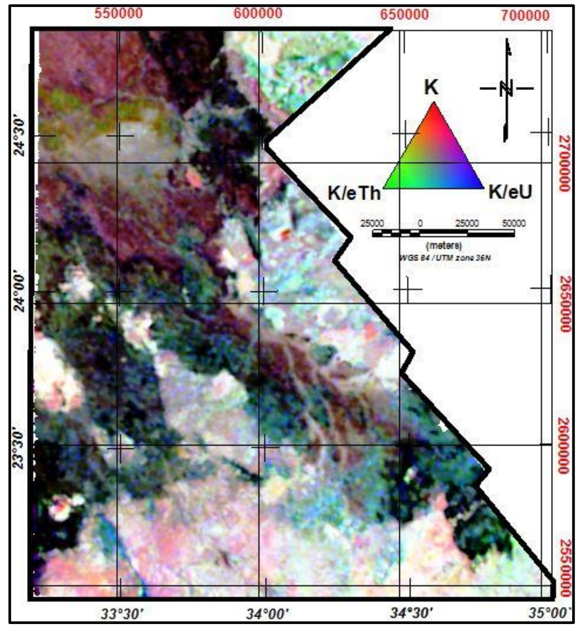


*Figure 11:* False colored Potassium Ternary Image of Wadi Jararah-Wadi Kharit area, South Eastern Desert, Egypt.

c) *Location of relatively high uraniferous concentration*

A large portion of the gamma-ray spectrometric interpretation aims essentially at identifying areas of real relative uranium enrichment and eliminating any false or misleading anomalies. This will allow the uraniferous provinces to be defined so that more detailed prospecting methods can be applied to the most promising area, which could be favorable sites for potential economic radioactive mineral deposits or associated non-radioactive metallic mineralization (Saunders and Potts, 1976). There are several methods of statistical data analysis to identify and outline such potential uraniferous provinces.

According to Potts, 1976, the value equal (X+3S) in each rock unit for eU, eU/eTh and eU/K variables (Table 2) was considered the threshold value which determines the occurrence of anomalous values. This technique is based on the fact that 99% of all measurements in any normal frequency distribution should fall within the range of (±) three standard deviations from arithmetic means (X±3S), which approximate the background. All values that occurred beyond this range are regarded as statistically significant (A. G. N. Gharieb and Gouda, 2007). Figure 12 shows the interpreted point anomaly map of the study area, which possesses values exceeding X+3S for eU, eU/eTh, and eU/K variables. Eight groups of statistically significant (anomalous) points can be distinguished on this map. Localities represent uraniferous anomalous zones which could be considered as a probable target of interest for ground follow-up investigation. These zones make sure and coincidence with the extractive radioactive zones from radioelement ternary image (Fig.8).

*Table 2:* Uraniferous anomalous distribution

| **Rock Units** | **Variables** | **Statistical Parameters** | **Rock Units** | **Variables** | **Statistical Parameters** |
|---|---|---|---|---|---|
| | | **X+3S** | | | **X+3S** |
| **Older Granite ($g_\alpha$)** | eU(ppm) | 72.83 | **Umm Barmil Formation (Kub)** | eU(ppm) | 47.03 |
| | eU/eTh | 0.88 | | eU/eTh | 0.63 |
| | eU/k | 4.95 | | eU/k | 9.59 |
| **Weathered Older Granite ($g_\alpha$w)** | eU(ppm) | 41.53 | **Dakhla Formation (Kud)** | eU(ppm) | 76.22 |
| | eU/eTh | 0.48 | | eU/eTh | 1.5 |
| | eU/k | 2.39 | | eU/k | 15.34 |
| **Younger Granite ($g_\beta$)** | eU(ppm) | 69.02 | **Quseir Formation (Kuq)** | eU(ppm) | 49.82 |
| | eU/eTh | 0.59 | | eU/eTh | 0.68 |
| | eU/k | 3.18 | | eU/k | 10.17 |

| | | | | | |
|---|---|---|---|---|---|
| **Weathered Younger Granite ($g_{\beta}w$)** | eU(ppm) | 48.5 | **Taref Formation (Kut)** | eU(ppm) | 32.99 |
| | eU/eTh | 0.56 | | eU/eTh | 0.62 |
| | eU/k | 3.05 | | eU/k | 10.02 |
| **Alkali- Feldspars Granitic Rocks ($g_{\gamma}$)** | eU(ppm) | 60.52 | **Duwi Formation (Kuw)** | eU(ppm) | 62.47 |
| | eU/eTh | 0.56 | | eU/eTh | 1.05 |
| | eU/k | 2.85 | | eU/k | ----- |
| **medium to high grade Metamorphic Rocks (gn)** | eU(ppm) | 19.85 | **Timsah Formation (Kux)** | eU(ppm) | 37.32 |
| | eU/eTh | ----- | | eU/eTh | 0.68 |
| | eU/k | ----- | | eU/k | 9.79 |
| **Melanocratic medium to high grade Metamorphic Rocks (gnl)** | eU(ppm) | 41.98 | **Metagabrro to Metadiorite (mg)** | eU(ppm) | ----- |
| | eU/eTh | 0.57 | | eU/eTh | 0.75 |
| | eU/k | 2.29 | | eU/k | 3.52 |
| **Gabbroic Rocks (gb)** | eU(ppm) | ----- | **Intrusive Metagabrro to Metadiorite (mgi)** | eU(ppm) | 28.36 |
| | eU/eTh | 0.73 | | eU/eTh | ----- |
| | eU/k | ----- | | eU/k | 2.35 |
| **Abu 'Aggag Formation (Ku)** | eU(ppm) | 36.68 | **Ophiolitic Metagabrro (mgo)** | eU(ppm) | 20.49 |
| | eU/eTh | 0.76 | | eU/eTh | 0.78 |
| | eU/k | 10.17 | | eU/k | ----- |
| **Metasediments (ms)** | eU(ppm) | 48.28 | **Tertiary Volcanics (vb)** | eU(ppm) | 69.05 |
| | eU/eTh | 0.64 | | eU/eTh | ----- |
| | eU/k | 4 | | eU/k | 2.27 |
| **Metavolcanics and MetaPyroclastics (mva)** | eU(ppm) | 64.21 | **Dokhan Volcanics (vd)** | eU(ppm) | 32.82 |
| | eU/eTh | 0.69 | | eU/eTh | 1.12 |
| | eU/k | 3.8 | | eU/k | 6.17 |
| **Quaternary deposits (Q)** | eU(ppm) | 47.95 | **Natash Volcanics (vn)** | eU(ppm) | 40.11 |
| | eU/eTh | 0.83 | | eU/eTh | 0.54 |
| | eU/k | 10.01 | | eU/k | 5.01 |
| **Quaternary Sand Dunes (Qd)** | eU(ppm) | 31.23 | **Trachyte Plugs and Sheets (vt)** | eU(ppm) | ----- |
| | eU/eTh | 0.89 | | eU/eTh | ----- |
| | eU/k | 6.12 | | eU/k | 4.17 |
| **Wadi deposits (Qw)** | eU(ppm) | 47.21 | **Post-Hammamat Felsite (vf)** | eU(ppm) | ----- |
| | eU/eTh | 0.67 | | eU/eTh | 0.46 |
| | eU/k | 8.87 | | eU/k | ----- |
| **Pliocene Deposits (Tpl)** | eU(ppm) | 87.2 | **Ring Complex (rc)** | eU(ppm) | 111.7 |
| | eU/eTh | 1.32 | | eU/eTh | 0.77 |
| | eU/k | 15.62 | | eU/k | 5.24 |

*Zone 1:* uraniferous anomalous are concentrated in Dokhan volcanic, Natash volcanic, and granitic rocks which associated with Urf Abu Hamam area (radioactive zone) at the northeastern corner and trending NE-SW.

*Zone 2:* uraniferous anomalous concentrated in Duwi Fm, Dakhla Fm, and Pliocene deposited which associated with G. Al Maghraby and east G. Al Maghraby (the highest uranium concentration) at the northwestern part of the study area and trending E-W.

*Zone 3:* anomalies of eU only are concentrated in older granite rock which associated with, G. Abu Gihan (radioactive zone) at the northwestern part of the study area and trending NW-SE.

*Zone 4:* anomalies of eU and eU/K are focused in Natash volcanics and granitic rocks which associated with, Homor Akarim, Natash volcanics, G. Ghurab Ar Rayan, and G. Ghurab Al Atshan (radioactive zones) at the northeastern part of the study area and trending NE-SW.

*Zone 5:* anomalies of eU and eU/K are focused in younger granite rocks which associated with G. Nikeiba (radioactive zone) at the southeastern part of the study area and trending E-W.

*Zone 6:* anomalies mainly of eU and some eU/K are concentrated in younger granite rocks which associated with G. Dihmit (radioactive zone) at the southwestern part of the study area and trending E-W.

*Zone 7:* uraniferous anomalous are concentrated in granitic rocks, ring complex, meta-gabbro, meta-volcanic, and Abu Aggag Fm which associated with G. Abu Maru and G. Umm Naqa at the southwestern corner of the study area and trending NW-SE.

*Zone 8:* uraniferous anomalous are concentrated in granitic rocks, Abu Aggag Fm, Timsah Fm, Umm Barmil Fm, and quaternary deposits which associated with G. Uqab El Nugum (radioactive zone), G. Kalat, G. Amreit, and G. Abraq at the southeastern corner of the study area and trending NW-SE.

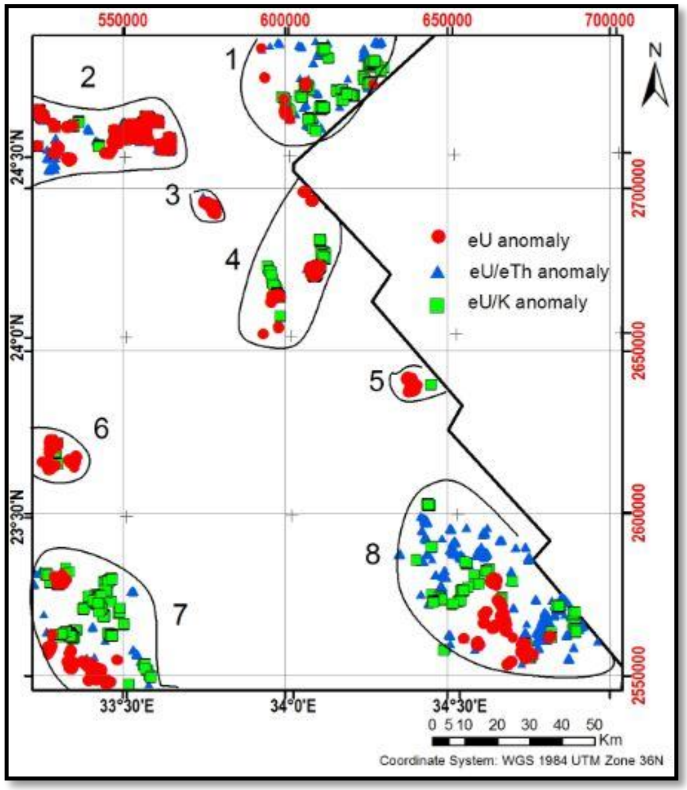


*Figure 12:* Spatial distribution of uraniferous concentration of Wadi Jararah-Wadi Kharit area, South Eastern Desert, Egypt.

d) *Landsat-8 Images*

i. *Band Ratios*

Band ratio is a multispectral image processing method that includes the division of one spectral band by another. This division results in the ratio of spectral reflectance measured in another spectral band. Identical surface materials can give different brightness values because of the topographic slope and aspect, shadows or seasonal changes in sunlight illumination angle and intensity. These variances affect the viewer's interpretations and may lead to misguided results. Here the author used various bands of Landsat 8 satellite imagery for band ratio which related to airborne radioactive zones. Band ratio's such as b6/b7, b6/b5…..and so on, are used to discriminate hydrothermal alteration and its relation with airborne radioactive zones.

Tested different kinds of band ratios that show a different kind of alterations such as:

1. Hydroxyl-bearing minerals (clay minerals) alteration showed tie relationship (only at the named areas) between it and airborne radioactive zones which illustrated in (Fig.13) as:
    a) G. Uqab El Nugum. b) G. Umm Naqa. c) G. Dihmit and d) Sikait El Jallabah area.
2. Sericitization alteration showed tie relationship (only at the named areas) between it and airborne radioactive zones which illustrated in (Fig.14) as:
    a) G.Uqab El Nugum. b) G. Umm Naqa. c) G. Dihmit. d) G. Ghurab Al Atshan. e) G. Ghurab Ar Rayan and f) Homor Akarim area.

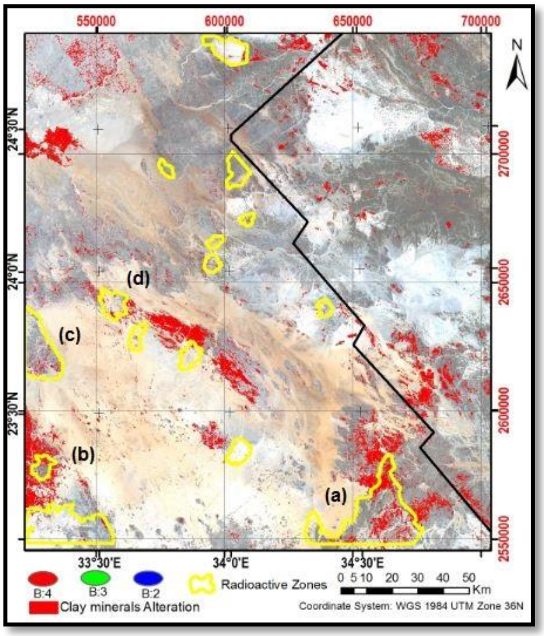


*Figure 13:* Band ratio 6/7, alteration represents as red pixels superimposed on natural color mosaic image (R: G: B 4:3:2).

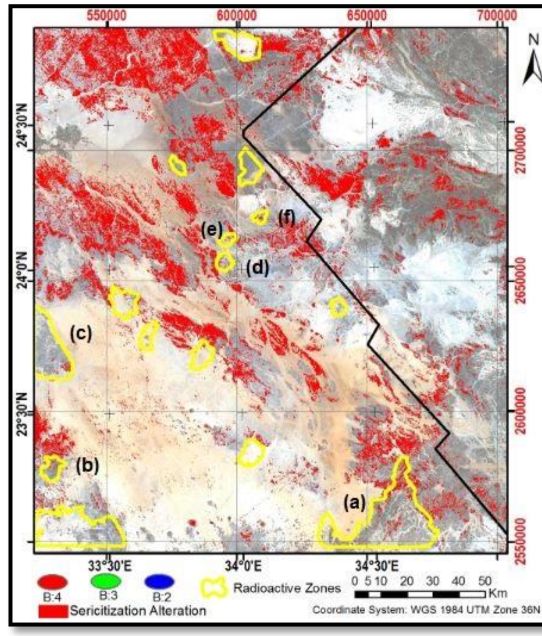


*Figure 14:* Band ratio 6/5, alteration represents as red pixels superimposed on natural color mosaic image (R: G: B 4:3:2).

3. Ferrous Iron oxides alteration displayed tie relationship (only at the named areas) between it and airborne radioactive zones which illustrated in (Fig.15) as:

a) Natash volcanics. b) G.Dihmit. c) G. Umm Naqa. d) G. Abu Marw. e) G. Ghadir-Ib. f) G. Uqab El Nugum and g) G. Nikeiba.

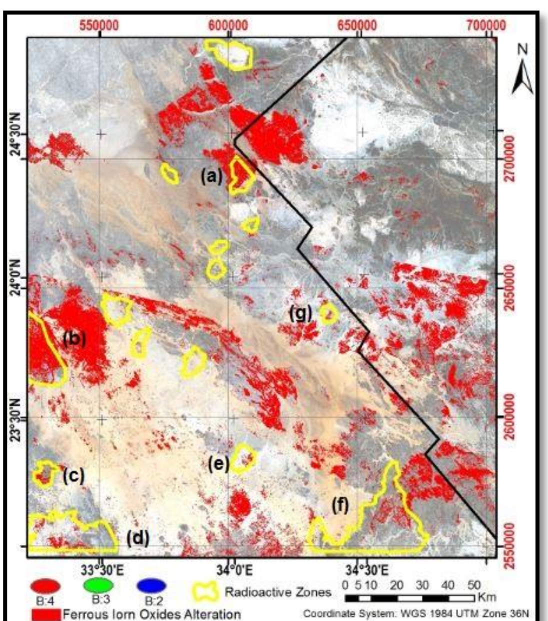


*Figure 15:* Band ratio 5/6, alteration represents as red pixels superimposed on natural color mosaic image (R: G: B 4:3:2).

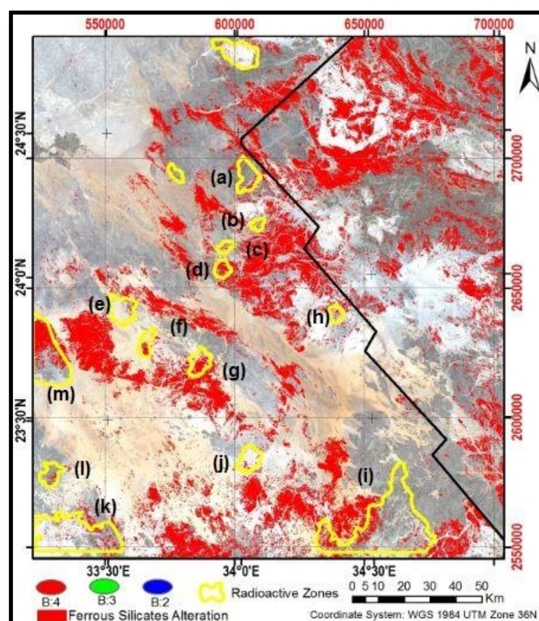


*Figure 16:* Band ratio 7/6, alteration represents as red pixels superimposed on natural color mosaic image (R: G: B 4:3:2).

4. Ferrous Silicate alteration exhibited tie relationship between it and all airborne radioactive zones except Urf Abu Hamam area which located at the center of the northern part of the study area. These radioactive zones are illustrated in (Fig.16) like:

   a) Natash Volcanics. b) Homor Akarim. c) G. Ghurab Ar Rayan. d) G. Ghurab Al Atshan. e) Sikhat Al Jallabah. f) Rawad El Kabsh. g) Khushaybat Umm Safi. h) G. Nikeiba. i) G. Uqab El Nugum. j) G. Ghadir-Ib. k) G. Abu Marw. l) G. Umm Naqa. m) G. Dihmit.

5. Ferric Iron alteration showed tie relationship (only at the named areas) between it and airborne radioactive zones which illustrated in (Fig.17) as:

   a) G. Nikeiba, and b) Rawad El Kabsh area.

6. Epidotization alteration showed tie relationship (only at the named areas) between it and airborne radioactive zones which illustrated in (Fig.18) as:

   a) Homor Akarim. b) G. Ghurab Ar Rayan. c) G. Ghurab Al Atshan. d) G. Dihmit. and e) G. Uqab El Nugum.

7. Chloritization alteration exhibited tie relationship (only at the named areas) between it and airborne radioactive zones which illustrated in (Fig.19) as:

   a) Homor Akarim. b) G. Ghurab Ar Rayan. c) G. Ghurab Al Atshan. d) Khushaybat Umm Safi. e) G. Abu Marw. and f) G. Uqab El Nugum.

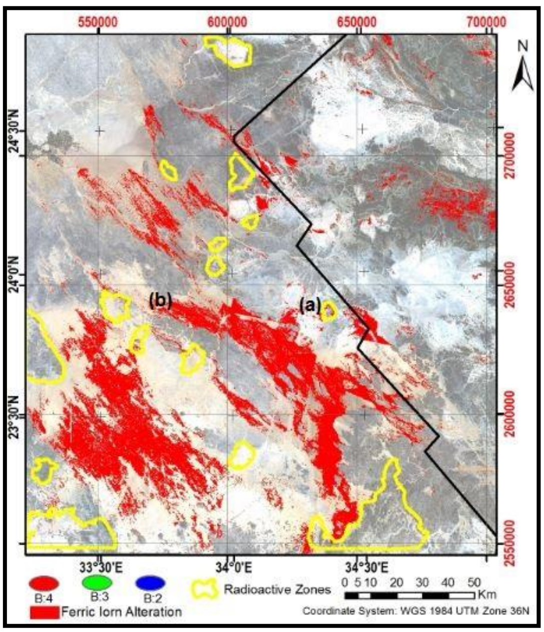


*Figure 17:* Band ratio 4/2, alteration represents as red pixels superimposed on natural color mosaic image (R: G: B 4:3:2).

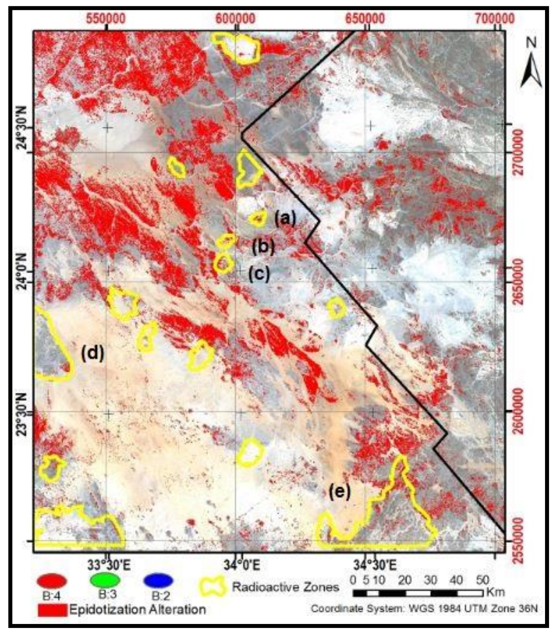


*Figure 18:* Band ratio 6/4, alteration represents as red pixels superimposed on natural color mosaic image (R: G: B 4:3:2).

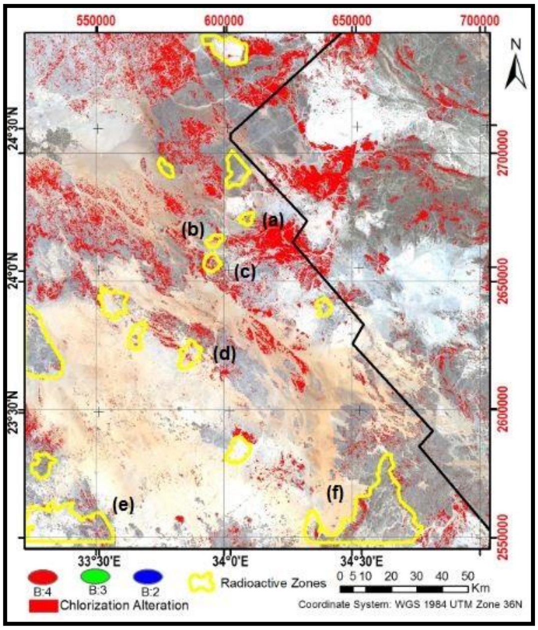


*Figure 19:* Band ratio 7/5, alteration represents as red pixels superimposed on natural color mosaic image (R: G: B 4:3:2).

e) *Crosta method*

Minimizing the number of spectral bands input for principal component analysis ensures that certain materials will not be unambiguous, mapped into only one of the principal component images. The methodology is called Crosta Technique or Feature-Oriented Principal Components Selection (FPCS). The method does not require detailed knowledge of the spectral properties of target materials; also no atmospheric or radiometric correction is needed. PCA on raw, un-stretched data is found to be effective in all cases. The main aim of PC analysis is to data remove redundancy in multispectral data. This technique can be applied on four or six bands of Landsat 8 data (Crosta and Moore 1989). For indicating Hydroxyl alteration two reflectances Landsat 8 bands (5, 6) and two absorption bands (2, 7) have been selected (Table 3). Applying these selected bands in a principal component analysis process for each scene separately to produced four PCs for VNIR-SWIR bands. Eigenvector statistics of input bands (Table 4) reflects that PC4 is a well indicator to Hydroxyl alteration, and by applying the thresholding process which applied in band ratio technique (Table 5) hydroxyl alterations areas will appear as red color (Fig.20). And for indicating Iron oxide alteration, two reflectance bands (4, 6) and two absorption bands (2, 5) have been selected (Table 3). Applying these selected bands in a principal component analysis process produced four PCs for VNIR-SWIR bands. Eigenvector statistics of input bands reflects that PC4 is a good indicator to Iron oxide alteration (Table 6) and the thresholding process (Table 7) show that Iorn oxide alterations areas will appear as red color (Fig.21).

*Table 3:* Input bands for FPCS (Crosta) Analysis of the selected alterations

| Type of Alteration | Landsat 8 ( selected bands) | |
|---|---|---|
| | High reflectance | Low reflectance “Absorption” |
| Hydroxyl Alteration | Band 5 | Band 2 |
| | Band 6 | Band 7 |
| Iron Oxide Alteration | Band 4 | Band 2 |
| | Band 6 | Band 5 |

*Table 4:* Eigenvector values statistics of selected Hydroxyl alteration bands for each scene separately

| Scene no. | PC | Band 2 | Band 5 | Band 6 | Band 7 | Eigenvalues | Eigen % |
|---|---|---|---|---|---|---|---|
| Scene A | PC1 | 0.385 | 0.515 | 0.549 | 0.535 | 22786.38 | 92.53 |
| | PC2 | 0.914 | -0.101 | -0.270 | -0.284 | 1335.55 | 5.42 |
| | PC3 | 0.123 | -0.850 | 0.401 | 0.318 | 431.34 | 1.75 |
| | PC4 | 0.020 | -0.046 | -0.682 | 0.730 | 72.83 | 0.30 |
| Scene B | PC1 | 0.482 | 0.503 | 0.510 | 0.505 | 23311.57 | 96.51 |
| | PC2 | 0.786 | 0.110 | -0.391 | -0.466 | 628.68 | 2.60 |
| | PC3 | 0.379 | -0.813 | 0.005 | 0.443 | 158.11 | 0.65 |
| | PC4 | -0.078 | 0.273 | -0.766 | 0.576 | 56.77 | 0.24 |
| Scene C | PC1 | 0.410 | 0.532 | 0.522 | 0.526 | 27350.86 | 93.75 |
| | PC2 | 0.910 | -0.182 | -0.263 | -0.264 | 1649.74 | 5.65 |
| | PC3 | -0.062 | 0.798 | -0.566 | -0.198 | 131.79 | 0.45 |
| | PC4 | -0.016 | 0.217 | 0.582 | -0.784 | 42.99 | 0.15 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Scene D | PC1 | 0.416 | 0.529 | 0.525 | 0.520 | 22226.96 | 90.30 |
| | PC2 | 0.904 | -0.151 | -0.282 | -0.284 | 2182.84 | 8.87 |
| | PC3 | -0.099 | 0.828 | -0.469 | -0.290 | 140.64 | 0.57 |
| | PC4 | -0.015 | 0.104 | 0.651 | -0.751 | 62.90 | 0.26 |

*Table 5:* Eigenvector values statistics of selected Iron Oxide alteration bands for each scene separately

| Scene no. | PC | Band 2 | Band 4 | Band 5 | Band 6 | Eigenvalues | Eigen % |
|---|---|---|---|---|---|---|---|
| Scene A | PC1 | 0.396 | 0.526 | 0.522 | 0.542 | 22535.88 | 92.80 |
| | PC2 | 0.887 | -0.013 | -0.270 | -0.375 | 1199.64 | 4.94 |
| | PC3 | 0.171 | -0.444 | -0.460 | 0.750 | 488.17 | 2.01 |
| | PC4 | 0.167 | -0.726 | 0.665 | -0.059 | 61.18 | 0.25 |
| Scene B | PC1 | 0.485 | 0.511 | 0.502 | 0.501 | 23564.32 | 97.32 |
| | PC2 | 0.711 | 0.132 | -0.148 | -0.674 | 484.29 | 2.00 |
| | PC3 | 0.465 | -0.405 | -0.575 | 0.538 | 149.30 | 0.62 |
| | PC4 | 0.205 | -0.747 | 0.629 | -0.068 | 14.67 | 0.06 |
| Scene C | PC1 | 0.413 | 0.533 | 0.529 | 0.515 | 27699.37 | 94.23 |
| | PC2 | 0.899 | -0.115 | -0.264 | -0.331 | 1519.43 | 5.17 |
| | PC3 | 0.111 | -0.423 | -0.429 | 0.790 | 165.76 | 0.56 |
| | PC4 | 0.097 | -0.723 | 0.683 | -0.030 | 12.17 | 0.04 |
| Scene D | PC1 | 0.424 | 0.539 | 0.520 | 0.510 | 22926.95 | 91.43 |
| | PC2 | 0.877 | -0.058 | -0.268 | -0.395 | 1950.29 | 7.78 |
| | PC3 | 0.186 | -0.473 | -0.407 | 0.759 | 184.30 | 0.73 |
| | PC4 | 0.129 | -0.695 | 0.702 | -0.088 | 14.74 | 0.06 |

So, PC1 is the "albedo and topography" image, PC2 describes the contrast between the SWIR and the visible region, PC3 is brightest for vegetation, and PC4 highlights hydroxyl-bearing minerals Table2. And in Table 3, PC1 is the "albedo" image, PC2 describes the contrast between the IR and the visible region, PC3 is brightest for vegetation, and PC4 highlights Iron Oxides.

*Table 6:* The thresholding values of Hydroxyl alteration selected bands for each scene separately

| Scene no. | Mean (**μ**) | Standard Deviation (**σ**) | Threshold Value |
|---|---|---|---|
| Scene (A) | 116.79 | 74.79 | 191.58 **(μ+1* σ)** |
| Scene (B) | 123.41 | 75.61 | 199.02 **(μ+1* σ)** |
| Scene (C) | 100.03 | 68.99 | 238.03 **(μ+2* σ)** |
| Scene (D) | 96.61 | 67.44 | 231.5 **(μ+2* σ)** |

*Table 7:* The thresholding values of Iron Oxide alteration selected bands for each scene separately

| Scene no. | Mean (**μ**) | Standard Deviation (**σ**) | Threshold Value **(μ+2* σ)** |
|---|---|---|---|
| Scene (A) | 120.20 | 53.06 | 226.32 |
| Scene (B) | 120.06 | 55.4 | 230.86 |
| Scene (C) | 140.43 | 53.9 | 248.23 |
| Scene (D) | 108.53 | 56.4 | 221.33 |

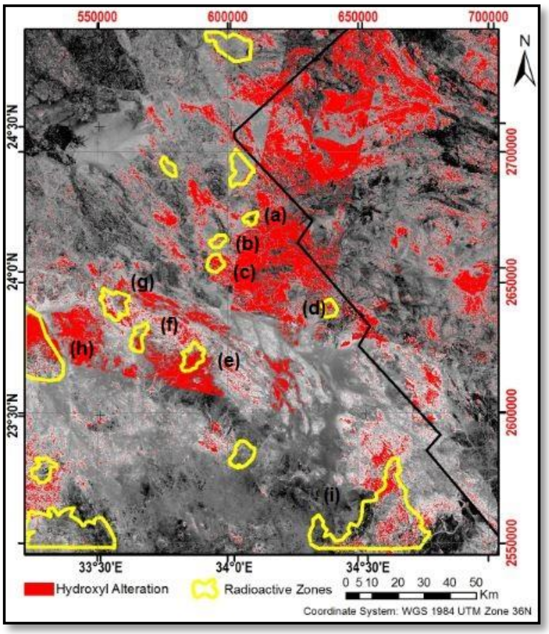


*Figure 20:* Resulted mosaic PC4 Hydroxyl alteration using FPCS (Crosta) technique.

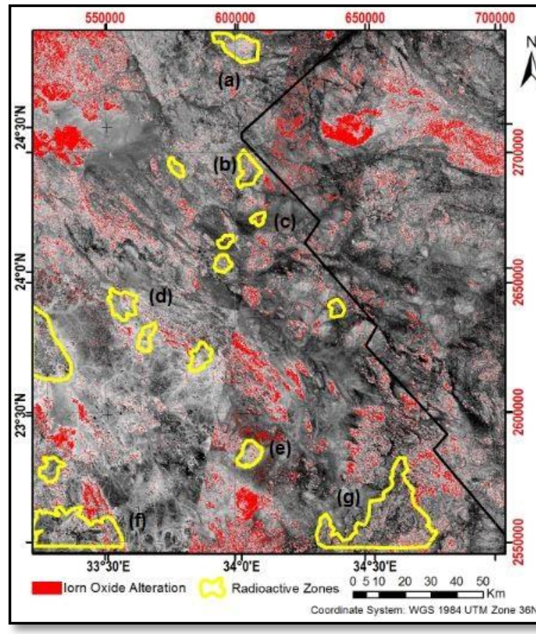


*Figure 21:* Resulted mosaic PC4 Iron Oxides alteration using FPCS (Crosta) technique.

So, from (Figs.20 & 21) we can indicate that:

1. In the Hydroxyl alteration (Fig.20), Homor Akarim area, G. Ghurab Ar Rayan, G. Ghurab Al Atshan, G. Nikeiba, Khushaybat Umm Safi, Rawad El Kabsh, Sikait El Jallabah, G. Dihmit, and G. Uqab El Nugum (a, b, c, d, e, f, g, h, and i, respectively) showed tie relationship with airborne radioactive zones.
2. And in the Iron Oxide alteration (Fig.21), Urf Abu Hamam area, Natash Volcanics, Homor Akarim area, Sikait El Jallabah, G. Ghadir_ib, G. Abu Marw, and G. Uqab El Nugum (a, b, c, d, e, f, and g, respectively) showed tie relationship with airborne radioactive zones.

These tie relationships give us an initial indication for a prospecting radioactive exploration for the same alterations distribution in the study area which didn't survey by airborne. (Fig.22) shows the promising radioactive 9 zones in the unsurvey area and the authors classified it as zones according to host rock where most of the host rocks are granitic rocks.

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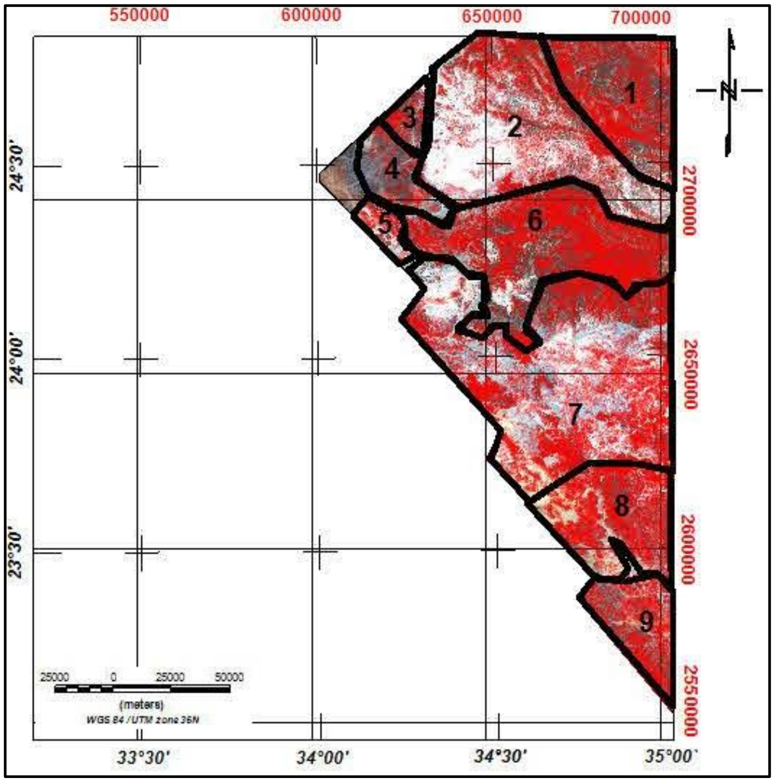


*Figure 22:* Showing the promising zones in the unsurvey area of Wadi Jararah-Wadi Kharit area, South Eastern Desert, Egypt.

- *Zone 1:* associated with granitic rocks like (G. el-Dob Neiya and G. Zabara), meta-volcanic, metasediments, and meta-gabbro rocks.
- *Zone 2:* Mainly associated with granitic rocks like (G. Duwaiq, G. Nuqus, G. Ras Sha'it, and G. El Faliq) with some meta-gabbro and volcanic rocks.
- *Zone 3:* mainly associated with ring complex (G. Abu El Khruq).
- *Zone 4:* mainly associated with Natash Volcanic.
- *Zone 5:* mainly associated with granitic rocks (east G. Muqtil)
- *Zone 6:* associated mainly with metavolcanic rocks and some granitic rocks like (G. Hasharib and G. Sheikh Shazly) with meta-gabbro.
- *Zone 7:* mainly correlated with granitic rocks like (G. el Homur and G. Humriet Muqbad) with meta-sediments and ring complex (G. Kahfa).
- *Zone 8:* associated with Cetaceous formation (Abu Aggag Fm and Timsah Fm) with some meta-sediments and meta-gabbro.
- *Zone 9:* mainly granitic rocks like (G. Hodein).

## IV. Conclusion

Airborne gamma-ray spectrometric measurements provide a good method for determining the radioactive zones at Wadi Jararah-Wadi Kharit area (in the surveyed area) through the interpretation of ternary images and the spatial distribution of the relatively high concentration of eU, eU/K, and eU/eTh variables, these zones are G.Abu Marw, G.Uqab El Nugum, G. Umm Naqa, G. Ghadir_ib, G.Dihmit Sikhat Al Jallabah, Rawad El Kabsh, Khushaybat Umm Safi, G.Nikeiba, G. Ghurab Al Atshan, G. Ghurab Ar Rayan, Homor Akarim, G.Abu Gihan, Urf Abu Hamam area, and Natash Volcanics. And through using different band ratios of Landsat images as (6/7, 4/2,…..and so on) and applying Crosta technique for indicating hydroxyl and iron oxide alterations, we could find tie relationship between radioactive zones (only at named zones) in the surveyed area and explore a new promising zones in the unsurvey areas like, G. el-Dob Neiya, G. Zabara, G. Duwaiq, G. Nuqus, G. Ras Sha'it, G. El Faliq, G. Abu El Khruq, G. el Homur, and G. Humriet Muqbad.

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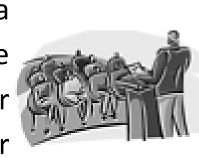

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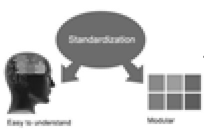


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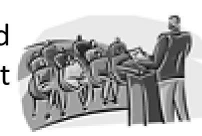

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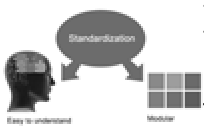


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Choice of the main keywords is the first tool of writing a research paper. Research paper writing is an art. Keyword search should be as strategic as possible.

One should start brainstorming lists of potential keywords before even beginning searching. Think about the most important concepts related to research work. Ask, "What words would a source have to include to be truly valuable in a research paper?" Then consider synonyms for the important words.

It may take the discovery of only one important paper to steer in the right keyword direction because, in most databases, the keywords under which a research paper is abstracted are listed with the paper.

**Numerical Methods**

Numerical methods used should be transparent and, where appropriate, supported by references.

**Abbreviations**

Authors must list all the abbreviations used in the paper at the end of the paper or in a separate table before using them.

**Formulas and equations**

Authors are advised to submit any mathematical equation using either MathJax, KaTeX, or LaTeX, or in a very high-quality image.

**Tables, Figures, and Figure Legends**

Tables: Tables should be cautiously designed, uncrowned, and include only essential data. Each must have an Arabic number, e.g., Table 4, a self-explanatory caption, and be on a separate sheet. Authors must submit tables in an editable format and not as images. References to these tables (if any) must be mentioned accurately.

**Figures**

Figures are supposed to be submitted as separate files. Always include a citation in the text for each figure using Arabic numbers, e.g., Fig. 4. Artwork must be submitted online in vector electronic form or by emailing it.

## Preparation of Eletronic Figures for Publication

Although low-quality images are sufficient for review purposes, print publication requires high-quality images to prevent the final product being blurred or fuzzy. Submit (possibly by e-mail) EPS (line art) or TIFF (halftone/ photographs) files only. MS PowerPoint and Word Graphics are unsuitable for printed pictures. Avoid using pixel-oriented software. Scans (TIFF only) should have a resolution of at least 350 dpi (halftone) or 700 to 1100 dpi (line drawings). Please give the data for figures in black and white or submit a Color Work Agreement form. EPS files must be saved with fonts embedded (and with a TIFF preview, if possible).

For scanned images, the scanning resolution at final image size ought to be as follows to ensure good reproduction: line art: >650 dpi; halftones (including gel photographs): >350 dpi; figures containing both halftone and line images: >650 dpi.

Color charges: Authors are advised to pay the full cost for the reproduction of their color artwork. Hence, please note that if there is color artwork in your manuscript when it is accepted for publication, we would require you to complete and return a Color Work Agreement form before your paper can be published. Also, you can email your editor to remove the color fee after acceptance of the paper.

## Tips for Writing a Good Quality Science Frontier Research Paper

Techniques for writing a good quality Science Frontier Research paper:

***1. Choosing the topic:*** In most cases, the topic is selected by the interests of the author, but it can also be suggested by the guides. You can have several topics, and then judge which you are most comfortable with. This may be done by asking several questions of yourself, like "Will I be able to carry out a search in this area? Will I find all necessary resources to accomplish the search? Will I be able to find all information in this field area?" If the answer to this type of question is "yes," then you ought to choose that topic. In most cases, you may have to conduct surveys and visit several places. Also, you might have to do a lot of work to find all the rises and falls of the various data on that subject. Sometimes, detailed information plays a vital role, instead of short information. Evaluators are human: The first thing to remember is that evaluators are also human beings. They are not only meant for rejecting a paper. They are here to evaluate your paper. So present your best aspect.

***2. Think like evaluators:*** If you are in confusion or getting demotivated because your paper may not be accepted by the evaluators, then think, and try to evaluate your paper like an evaluator. Try to understand what an evaluator wants in your research paper, and you will automatically have your answer. Make blueprints of paper: The outline is the plan or framework that will help you to arrange your thoughts. It will make your paper logical. But remember that all points of your outline must be related to the topic you have chosen.

***3. Ask your guides:*** If you are having any difficulty with your research, then do not hesitate to share your difficulty with your guide (if you have one). They will surely help you out and resolve your doubts. If you can't clarify what exactly you require for your work, then ask your supervisor to help you with an alternative. He or she might also provide you with a list of essential readings.

***4. Use of computer is recommended:*** As you are doing research in the field of science frontier then this point is quite obvious. Use right software: Always use good quality software packages. If you are not capable of judging good software, then you can lose the quality of your paper unknowingly. There are various programs available to help you which you can get through the internet.

***5. Use the internet for help:*** An excellent start for your paper is using Google. It is a wondrous search engine, where you can have your doubts resolved. You may also read some answers for the frequent question of how to write your research paper or find a model research paper. You can download books from the internet. If you have all the required books, place importance on reading, selecting, and analyzing the specified information. Then sketch out your research paper. Use big pictures: You may use encyclopedias like Wikipedia to get pictures with the best resolution. At Global Journals, you should strictly follow here.

***6. Bookmarks are useful:*** When you read any book or magazine, you generally use bookmarks, right? It is a good habit which helps to not lose your continuity. You should always use bookmarks while searching on the internet also, which will make your search easier.

***7. Revise what you wrote:*** When you write anything, always read it, summarize it, and then finalize it.

***8. Make every effort:*** Make every effort to mention what you are going to write in your paper. That means always have a good start. Try to mention everything in the introduction—what is the need for a particular research paper. Polish your work with good writing skills and always give an evaluator what he wants. Make backups: When you are going to do any important thing like making a research paper, you should always have backup copies of it either on your computer or on paper. This protects you from losing any portion of your important data.

***9. Produce good diagrams of your own:*** Always try to include good charts or diagrams in your paper to improve quality. Using several unnecessary diagrams will degrade the quality of your paper by creating a hodgepodge. So always try to include diagrams which were made by you to improve the readability of your paper. Use of direct quotes: When you do research relevant to literature, history, or current affairs, then use of quotes becomes essential, but if the study is relevant to science, use of quotes is not preferable.

***10. Use proper verb tense:*** Use proper verb tenses in your paper. Use past tense to present those events that have happened. Use present tense to indicate events that are going on. Use future tense to indicate events that will happen in the future. Use of wrong tenses will confuse the evaluator. Avoid sentences that are incomplete.

***11. Pick a good study spot:*** Always try to pick a spot for your research which is quiet. Not every spot is good for studying.

***12. Know what you know:*** Always try to know what you know by making objectives, otherwise you will be confused and unable to achieve your target.

***13. Use good grammar:*** Always use good grammar and words that will have a positive impact on the evaluator; use of good vocabulary does not mean using tough words which the evaluator has to find in a dictionary. Do not fragment sentences. Eliminate one-word sentences. Do not ever use a big word when a smaller one would suffice.

Verbs have to be in agreement with their subjects. In a research paper, do not start sentences with conjunctions or finish them with prepositions. When writing formally, it is advisable to never split an infinitive because someone will (wrongly) complain. Avoid clichés like a disease. Always shun irritating alliteration. Use language which is simple and straightforward. Put together a neat summary.

***14. Arrangement of information:*** Each section of the main body should start with an opening sentence, and there should be a changeover at the end of the section. Give only valid and powerful arguments for your topic. You may also maintain your arguments with records.

***15. Never start at the last minute:*** Always allow enough time for research work. Leaving everything to the last minute will degrade your paper and spoil your work.

***16. Multitasking in research is not good:*** Doing several things at the same time is a bad habit in the case of research activity. Research is an area where everything has a particular time slot. Divide your research work into parts, and do a particular part in a particular time slot.

***17. Never copy others' work:*** Never copy others' work and give it your name because if the evaluator has seen it anywhere, you will be in trouble. Take proper rest and food: No matter how many hours you spend on your research activity, if you are not taking care of your health, then all your efforts will have been in vain. For quality research, take proper rest and food.

***18. Go to seminars:*** Attend seminars if the topic is relevant to your research area. Utilize all your resources.

***19. Refresh your mind after intervals:*** Try to give your mind a rest by listening to soft music or sleeping in intervals. This will also improve your memory. Acquire colleagues: Always try to acquire colleagues. No matter how sharp you are, if you acquire colleagues, they can give you ideas which will be helpful to your research.

***20. Think technically:*** Always think technically. If anything happens, search for its reasons, benefits, and demerits. Think and then print: When you go to print your paper, check that tables are not split, headings are not detached from their descriptions, and page sequence is maintained.

***21. Adding unnecessary information:*** Do not add unnecessary information like "I have used MS Excel to draw graphs." Irrelevant and inappropriate material is superfluous. Foreign terminology and phrases are not apropos. One should never take a broad view. Analogy is like feathers on a snake. Use words properly, regardless of how others use them. Remove quotations. Puns are for kids, not grunt readers. Never oversimplify: When adding material to your research paper, never go for oversimplification; this will definitely irritate the evaluator. Be specific. Never use rhythmic redundancies. Contractions shouldn't be used in a research paper. Comparisons are as terrible as clichés. Give up ampersands, abbreviations, and so on. Remove commas that are not necessary. Parenthetical words should be between brackets or commas. Understatement is always the best way to put forward earth-shaking thoughts. Give a detailed literary review.

***22. Report concluded results:*** Use concluded results. From raw data, filter the results, and then conclude your studies based on measurements and observations taken. An appropriate number of decimal places should be used. Parenthetical remarks are prohibited here. Proofread carefully at the final stage. At the end, give an outline to your arguments. Spot perspectives of further study of the subject. Justify your conclusion at the bottom sufficiently, which will probably include examples.

***23. Upon conclusion:*** Once you have concluded your research, the next most important step is to present your findings. Presentation is extremely important as it is the definite medium though which your research is going to be in print for the rest of the crowd. Care should be taken to categorize your thoughts well and present them in a logical and neat manner. A good quality research paper format is essential because it serves to highlight your research paper and bring to light all necessary aspects of your research.

## Informal Guidelines of Research Paper Writing

***Key points to remember:***

- Submit all work in its final form.
- Write your paper in the form which is presented in the guidelines using the template.
- Please note the criteria peer reviewers will use for grading the final paper.

**Final points:**

One purpose of organizing a research paper is to let people interpret your efforts selectively. The journal requires the following sections, submitted in the order listed, with each section starting on a new page:

*The introduction:* This will be compiled from reference matter and reflect the design processes or outline of basis that directed you to make a study. As you carry out the process of study, the method and process section will be constructed like that. The results segment will show related statistics in nearly sequential order and direct reviewers to similar intellectual paths throughout the data that you gathered to carry out your study.

**The discussion section:**

This will provide understanding of the data and projections as to the implications of the results. The use of good quality references throughout the paper will give the effort trustworthiness by representing an alertness to prior workings.

Writing a research paper is not an easy job, no matter how trouble-free the actual research or concept. Practice, excellent preparation, and controlled record-keeping are the only means to make straightforward progression.

**General style:**

Specific editorial column necessities for compliance of a manuscript will always take over from directions in these general guidelines.

**To make a paper clear:** Adhere to recommended page limits.

*Mistakes to avoid:*

- Insertion of a title at the foot of a page with subsequent text on the next page.
- Separating a table, chart, or figure—confine each to a single page.
- Submitting a manuscript with pages out of sequence.
- In every section of your document, use standard writing style, including articles ("a" and "the").
- Keep paying attention to the topic of the paper.
- Use paragraphs to split each significant point (excluding the abstract).
- Align the primary line of each section.
- Present your points in sound order.
- Use present tense to report well-accepted matters.
- Use past tense to describe specific results.
- Do not use familiar wording; don't address the reviewer directly. Don't use slang or superlatives.
- Avoid use of extra pictures—include only those figures essential to presenting results.

**Title page:**

Choose a revealing title. It should be short and include the name(s) and address(es) of all authors. It should not have acronyms or abbreviations or exceed two printed lines.

**Abstract:** This summary should be two hundred words or less. It should clearly and briefly explain the key findings reported in the manuscript and must have precise statistics. It should not have acronyms or abbreviations. It should be logical in itself. Do not cite references at this point.

An abstract is a brief, distinct paragraph summary of finished work or work in development. In a minute or less, a reviewer can be taught the foundation behind the study, common approaches to the problem, relevant results, and significant conclusions or new questions.

Write your summary when your paper is completed because how can you write the summary of anything which is not yet written? Wealth of terminology is very essential in abstract. Use comprehensive sentences, and do not sacrifice readability for brevity; you can maintain it succinctly by phrasing sentences so that they provide more than a lone rationale. The author can at this moment go straight to shortening the outcome. Sum up the study with the subsequent elements in any summary. Try to limit the initial two items to no more than one line each.

*Reason for writing the article—theory, overall issue, purpose.*

- Fundamental goal.
- To-the-point depiction of the research.
- Consequences, including definite statistics—if the consequences are quantitative in nature, account for this; results of any numerical analysis should be reported. Significant conclusions or questions that emerge from the research.

**Approach:**

- o Single section and succinct.
- o An outline of the job done is always written in past tense.
- o Concentrate on shortening results—limit background information to a verdict or two.
- o Exact spelling, clarity of sentences and phrases, and appropriate reporting of quantities (proper units, important statistics) are just as significant in an abstract as they are anywhere else.

**Introduction:**

The introduction should "introduce" the manuscript. The reviewer should be presented with sufficient background information to be capable of comprehending and calculating the purpose of your study without having to refer to other works. The basis for the study should be offered. Give the most important references, but avoid making a comprehensive appraisal of the topic. Describe the problem visibly. If the problem is not acknowledged in a logical, reasonable way, the reviewer will give no attention to your results. Speak in common terms about techniques used to explain the problem, if needed, but do not present any particulars about the protocols here.

*The following approach can create a valuable beginning:*

- Explain the value (significance) of the study.
- Defend the model—why did you employ this particular system or method? What is its compensation? Remark upon its appropriateness from an abstract point of view as well as pointing out sensible reasons for using it.
- Present a justification. State your particular theory(-ies) or aim(s), and describe the logic that led you to choose them.
- Briefly explain the study's tentative purpose and how it meets the declared objectives.

**Approach:**

Use past tense except for when referring to recognized facts. After all, the manuscript will be submitted after the entire job is done. Sort out your thoughts; manufacture one key point for every section. If you make the four points listed above, you will need at least four paragraphs. Present surrounding information only when it is necessary to support a situation. The reviewer does not desire to read everything you know about a topic. Shape the theory specifically—do not take a broad view.

As always, give awareness to spelling, simplicity, and correctness of sentences and phrases.

**Procedures (methods and materials):**

This part is supposed to be the easiest to carve if you have good skills. A soundly written procedures segment allows a capable scientist to replicate your results. Present precise information about your supplies. The suppliers and clarity of reagents can be helpful bits of information. Present methods in sequential order, but linked methodologies can be grouped as a segment. Be concise when relating the protocols. Attempt to give the least amount of information that would permit another capable scientist to replicate your outcome, but be cautious that vital information is integrated. The use of subheadings is suggested and ought to be synchronized with the results section.

When a technique is used that has been well-described in another section, mention the specific item describing the way, but draw the basic principle while stating the situation. The purpose is to show all particular resources and broad procedures so that another person may use some or all of the methods in one more study or referee the scientific value of your work. It is not to be a step-by-step report of the whole thing you did, nor is a methods section a set of orders.

**Materials:**

*Materials may be reported in part of a section or else they may be recognized along with your measures.*

**Methods:**

- Report the method and not the particulars of each process that engaged the same methodology.
- Describe the method entirely.
- To be succinct, present methods under headings dedicated to specific dealings or groups of measures.
- Simplify—detail how procedures were completed, not how they were performed on a particular day.
- If well-known procedures were used, account for the procedure by name, possibly with a reference, and that's all.

**Approach:**

It is embarrassing to use vigorous voice when documenting methods without using first person, which would focus the reviewer's interest on the researcher rather than the job. As a result, when writing up the methods, most authors use third person passive voice.

Use standard style in this and every other part of the paper—avoid familiar lists, and use full sentences.

**What to keep away from:**

- Resources and methods are not a set of information.
- Skip all descriptive information and surroundings—save it for the argument.
- Leave out information that is immaterial to a third party.

**Results:**

The principle of a results segment is to present and demonstrate your conclusion. Create this part as entirely objective details of the outcome, and save all understanding for the discussion.

The page length of this segment is set by the sum and types of data to be reported. Use statistics and tables, if suitable, to present consequences most efficiently.

You must clearly differentiate material which would usually be incorporated in a study editorial from any unprocessed data or additional appendix matter that would not be available. In fact, such matters should not be submitted at all except if requested by the instructor.

**Content:**

- Sum up your conclusions in text and demonstrate them, if suitable, with figures and tables.
- In the manuscript, explain each of your consequences, and point the reader to remarks that are most appropriate.
- Present a background, such as by describing the question that was addressed by creation of an exacting study.
- Explain results of control experiments and give remarks that are not accessible in a prescribed figure or table, if appropriate.
- Examine your data, then prepare the analyzed (transformed) data in the form of a figure (graph), table, or manuscript.

**What to stay away from:**

- Do not discuss or infer your outcome, report surrounding information, or try to explain anything.
- Do not include raw data or intermediate calculations in a research manuscript.
- Do not present similar data more than once.
- A manuscript should complement any figures or tables, not duplicate information.
- Never confuse figures with tables—there is a difference.

**Approach:**

As always, use past tense when you submit your results, and put the whole thing in a reasonable order.

Put figures and tables, appropriately numbered, in order at the end of the report.

If you desire, you may place your figures and tables properly within the text of your results section.

**Figures and tables:**

If you put figures and tables at the end of some details, make certain that they are visibly distinguished from any attached appendix materials, such as raw facts. Whatever the position, each table must be titled, numbered one after the other, and include a heading. All figures and tables must be divided from the text.

**Discussion:**

The discussion is expected to be the trickiest segment to write. A lot of papers submitted to the journal are discarded based on problems with the discussion. There is no rule for how long an argument should be.

Position your understanding of the outcome visibly to lead the reviewer through your conclusions, and then finish the paper with a summing up of the implications of the study. The purpose here is to offer an understanding of your results and support all of your conclusions, using facts from your research and generally accepted information, if suitable. The implication of results should be fully described.

Infer your data in the conversation in suitable depth. This means that when you clarify an observable fact, you must explain mechanisms that may account for the observation. If your results vary from your prospect, make clear why that may have happened. If your results agree, then explain the theory that the proof supported. It is never suitable to just state that the data approved the prospect, and let it drop at that. Make a decision as to whether each premise is supported or discarded or if you cannot make a conclusion with assurance. Do not just dismiss a study or part of a study as "uncertain."

Research papers are not acknowledged if the work is imperfect. Draw what conclusions you can based upon the results that you have, and take care of the study as a finished work.

- You may propose future guidelines, such as how an experiment might be personalized to accomplish a new idea.
- Give details of all of your remarks as much as possible, focusing on mechanisms.
- Make a decision as to whether the tentative design sufficiently addressed the theory and whether or not it was correctly restricted. Try to present substitute explanations if they are sensible alternatives.
- One piece of research will not counter an overall question, so maintain the large picture in mind. Where do you go next? The best studies unlock new avenues of study. What questions remain?
- Recommendations for detailed papers will offer supplementary suggestions.

**Approach:**

When you refer to information, differentiate data generated by your own studies from other available information. Present work done by specific persons (including you) in past tense.

Describe generally acknowledged facts and main beliefs in present tense.

## The Administration Rules

Administration Rules to Be Strictly Followed before Submitting Your Research Paper to Global Journals Inc.

*Please read the following rules and regulations carefully before submitting your research paper to Global Journals Inc. to avoid rejection*.

*Segment draft and final research paper:* You have to strictly follow the template of a research paper, failing which your paper may get rejected. You are expected to write each part of the paper wholly on your own. The peer reviewers need to identify your own perspective of the concepts in your own terms. Please do not extract straight from any other source, and do not rephrase someone else's analysis. Do not allow anyone else to proofread your manuscript.

*Written material:* You may discuss this with your guides and key sources. Do not copy anyone else's paper, even if this is only imitation, otherwise it will be rejected on the grounds of plagiarism, which is illegal. Various methods to avoid plagiarism are strictly applied by us to every paper, and, if found guilty, you may be blacklisted, which could affect your career adversely. To guard yourself and others from possible illegal use, please do not permit anyone to use or even read your paper and file.

## Criterion for Grading a Research Paper (Compilation) by Global Journals

**Please note that following table is only a Grading of "Paper Compilation" and not on "Performed/Stated Research" whose grading solely depends on Individual Assigned Peer Reviewer and Editorial Board Member. These can be available only on request and after decision of Paper. This report will be the property of Global Journals.**

| Topics | Grades | | |
|---|---|---|---|
| | **A-B** | **C-D** | **E-F** |
| ***Abstract*** | Clear and concise with appropriate content, Correct format. 200 words or below | Unclear summary and no specific data, Incorrect form<br><br>Above 200 words | No specific data with ambiguous information<br><br>Above 250 words |
| ***Introduction*** | Containing all background details with clear goal and appropriate details, flow specification, no grammar and spelling mistake, well organized sentence and paragraph, reference cited | Unclear and confusing data, appropriate format, grammar and spelling errors with unorganized matter | Out of place depth and content, hazy format |
| ***Methods and Procedures*** | Clear and to the point with well arranged paragraph, precision and accuracy of facts and figures, well organized subheads | Difficult to comprehend with embarrassed text, too much explanation but completed | Incorrect and unorganized structure with hazy meaning |
| ***Result*** | Well organized, Clear and specific, Correct units with precision, correct data, well structuring of paragraph, no grammar and spelling mistake | Complete and embarrassed text, difficult to comprehend | Irregular format with wrong facts and figures |
| ***Discussion*** | Well organized, meaningful specification, sound conclusion, logical and concise explanation, highly structured paragraph reference cited | Wordy, unclear conclusion, spurious | Conclusion is not cited, unorganized, difficult to comprehend |
| ***References*** | Complete and correct format, well organized | Beside the point, Incomplete | Wrong format and structuring |

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save our planet

# Global Journal of Science Frontier Research

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