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Chiefdom Ecodynamics

Mapping Aquifer Bifurcation

Highlights

Multi-Functional Landscape

Rural Inhabitants Participation

Discovering Thoughts, Inventing Future

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Multi-Functional Landscape Networks Identification by Impedance based Mapping Method: Two Case Studies at State Level Scale

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Abstract- The study comparatively applies a methodology for GIS-based development of landscape networks on a supraregional scale. The core strategy applied is to use impedance / least cost path concept for the delineation of corridors between hubs. The developed methodology applied in two different case studies in the territory of Kurdistan Region and for the federal state territory of Baden-Württemberg (Federal Republic of Germany). Both studies use different motivations, intentions and methodologies. For the case study in Kurdistan Region a combination of biodiversity preservation and managing cultural/historic/recreational landscape ecosystem services lead to a multifunctional network, in the case of Baden-Württemberg landscape permeability considerations lead to a network from which benefits in regard to recreation and habitat connectivity are expected. The article follows a general methodological concept and suggests as a conclusion to think about landscape in a dual network structure.

Keywords: *landscape networks; GIS; impedance based mapping*.

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Sawsan Mohamed [α] & Dr. Rer. Nat. hans-georg schwarz-V. raumer [σ]

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Keywords: landscape networks; GIS; impedance based mapping.

I. Introduction

a) *Background and Objectives*

To understand and to develop landscapes at a regional scale it is not enough to consider landscape as a mosaic of different land-cover, land-use or ecosystems. Landscape ecology but also regional geography emphasize, that we have to think about landscape in terms of spatial relationship, linkages and exchange. The conceptual framework for landscape cognition and thus for landscape development must - besides a spatio-dynamic view - include a perspective of network thinking. This kind of thinking reflects universal principles of spatial organization, and recently culminates in the debate and promotion of Green Infrastructure (GI) as a target for comprehensive spatial planning and as an appropriate idea for sustainable and resilient spatial structures. Landscape network thinking breaks with a choropleth model of landscape units when addressing and describing landscapes, and suggests a spatial model separating nodes or hubs from linkages or corridors, both delineated from a background on which the network is drawn as a figure (see fig. 1).

As implied, the intention of introducing the idea of landscape networks is a constructive lay down of a planning vision, and there are several reasons to prefer landscape network delineation. In general a first reason is to enable exchange between hubs. A second - related to the first – is to support function and preservation of hubs. In our study the following backgrounds are identified in particular:

This two contrasting types of intentions to think about landscape networks, provokes by presenting two different examples for what the meaning of landscape network thinking can be. However, the aim is to sketch the universality of a proposed methodological framework, and try to present the comparison of two geographically completely different regions brings up a wider range of methodological particularities inherent to the suggested approach of landscape network thinking.

So the target of this article is to discuss a unified methodology for multifunctional landscape network modelling and to demonstrate with different case studies its successful application. The method developed called, Impedance Based Network Mapping and apply it in two different research studies at the same spatial scale. The first research, applied the method for developing multi-functional green corridors that enhance preservation of biodiversity and geodiversity as well as conservation of landscape heritage and historic environment in Kurdistan Region (Mohamed 2011). The second research investigates the degree of dissection of landscape corridors at state level in Baden-Württemberg (Mohamed 2011). The different case studies can't be highlighted as an elaborated geographical comparative study but rather as an evidence of visibility and applicability of the method at supra-regional scale regardless to the distinctive and different natural and cultural resources and characteristics of each research area.

b) *Kurdistan Region (KR)*

One of the fundamental consequences of urbanization can be found in the loss of permeability of open space due to the development of settlement networks and urban growth. Ecological (e.g. bio-

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connectivity, remoteness, air exchange and uncontaminated soils and water) as well as other landscape qualities and services like suitability for recreation, cultural and agricultural functions or visual integrity, are affected by the landscape being dissected with roads, settlements and other infrastructure facilities. At a national scale, there was no legislation on biodiversity preservation areas till 2013. None the less the protection of natural preservation areas called Protected Areas (as isolated island) was a common practice without regulatory background in some areas in Kurdistan since the 1960s. At both national and regional scale managing manmade landscape (forest, agricultural habitat, fishery and etc.) was regulated by urban development restriction and limitation laws since the 1970s and by environmental laws since 1997. At a national scale a new institutional framework is developed for managing Natural Protected Areas in 2009 by the Ministry of Environment. At a regional scale since 2008 the Law of Environmental Protection and Improvement is issued and the protection of natural biodiversity areas is included. This was a natural outcome of the rapid economical and touristic development, due to high landscape qualities and recreation services in the heart of those rich biodiversity areas, since 1998 in KR. The rules - also as an adaption response to climate change and migratory policy for preventing desertification - include the construction policy of developing gardens, natural protective areas and general parks, and maintain natural sites which have an extensive heritage. Up to now there is no clear planning practice or regulation, neither at the national nor at the regional scale, covering ecological exchange or ecological network coherence. Moreover the Natural Protected Areas are identified but preservation and protection measures are rarely implemented.

c) *Baden-Württemberg (BW)*

Urban growth and and particularly transportation infrastructure development are the main cause of dissection, loss of permeability and visual integrity in landscape network. So in large parts of BW responding to urbanization and densification of the settlement network an appropriate counter-structure must be defined. For decades it was enough to think in patterns of scattered islands for preservation of valuable landscapes and for preserving big areas sufficient in size and lack of disturbance. In Germany e.g. areas of 100 km² which are nearly undisturbed by traffic had and still have an important role in national policy and planning guidelines. These areas nowadays got the role of hubs in migration networks for rare mammals.

d) *Relevant Approaches*

Since Wilson and Willis (1975) theories of equilibrium island biogeography, meta population, the ecological coherence and its integrity are under investigation. It has been proven that isolated reserves as self-contained independent entities are not enough for biodiversity and population conservation regardless to the intensity of management and protection measures (Bennett and Mulongoy 2006). Since then streams of research investigating and examining the connections among patches at landscape scale were developed: starting with the traditional ecological practice in late 1970s (Wilson and Willis 1975), continued by approaches which combine landscape structure, function, and dynamic pattern and in which ecological flow systems are highlighted in the 1980s and early 1990s (Forman 1983, Harms and Forman, 1989, Holland et al. 1991, Wiens 1992, Dramstad et al. 1996, Puth and Wilson 2001), and then being proceeded up to recent years by suggesting supra-regional and supra-national ecological networks following the idea of a patch-corridor structure within a broader landscape matrix (Bennett 1991, Smith and Maltby 2003, Bennett 2004, Böttcher et al. 2005, IUCN 2005, Bennett and Mulongoy 2006, (Schwarz-v.Raumer and Esswein 2010). sometimes extended by the classification of buffers and links (Fig. 1).

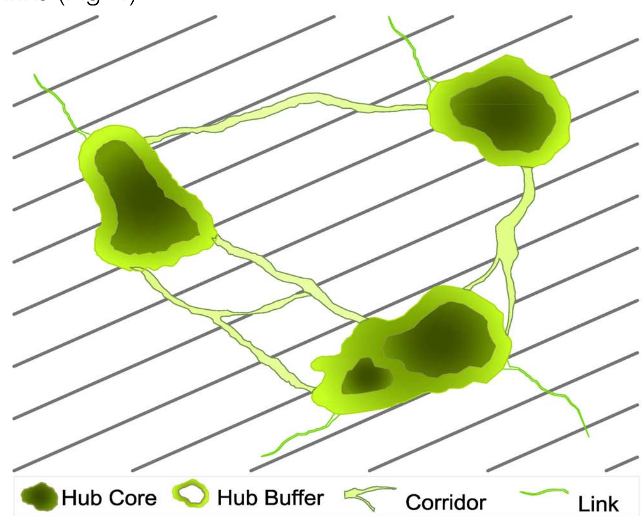

Fig. 1: General structure of ecological networks

In parallel to the growing idea of ecological networks, fragmentation and connectivity got a focus of landscape related ecology. The anthropogenic alteration of the landscape mosaic by urban development, transportation and other infrastructures as well as large scale agriculture practiced on big and intensively used plots or homogeneous afforestation using non-native species, landscapes and corridors have been fragmented, dissected, lost and/or modified (Loney and Hobbs 1991, Forman 1995). Ecological connectivity, defined by Taylor et al. (1993) as the degree to which the landscape facilitates or impedes movement among resource patches, is - besides eco-integrity – identified as the most significant feature for biodiversity preservation that enhances resiliency, population,

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community, and ecosystem processes (Noss and Coperrider 1994, Gilbert-Norton et al. 2010, Pino and Marull 2012).

Three basic concepts indicate eco-connectivity and its effectivity at regional and supra-regional scale: (1) GIS based mapping, (2) considerations about permeability depending on dissection and fragmentation and (3) approaches that take the perspective of moving individuals and evaluate landscapes based on specific preferences.

e) GIS based Mapping

The utilization and application of GIS in environmental planning and natural resource management has proved successful application since early 1990s (Lathrop and Bognar 1998). The classical application of GIS leads to Green Infrastructure (GI) or ecosystem mapping and traditional ecological practice for biodiversity conservation (e.g. site selection process for habitats) often supported by overlaying and buffering of different thematic layers (Lathrop and Bognar 1998, Hoctor et al. 2000, Wickham et al. 2011).

f) Permeability Indication

Within the field of permeability concepts which evaluate quantitatively landscape fragmentation and the degree of permeability, the measurement ´effective mesh size´ developed by Jaeger (2000) and applied for different case study areas at supra-regional scale (Jaeger 2000, Esswein and et al. 2002, Roedenbeck et al. 2005, Moser et al. 2007, Girvetz and et al. 2008) got prominent. The fragmentation geometry is identified by the specification of the landscape elements that cause dissection. Another method to identify permeability comes from approaches like Morphological Spatial Pattern Analysis (MSPA), the morphological analysis by geometrical analysis of morphological pattern that incorporate land-cover change information. It identifies hubs and links by - based on mathematical equations - creating related structural classes and creates the spatial relationship within the features of the single land-cover (Wickham et al. 2011).

g) Movement based Approaches

Beside individual-based simulations (DeAngelis and Grimm 2014) the application of least cost path technique for landscape fragmentation studies, structural and/or functional connectivity analyses, corridor delineation, scenario building and land management decision support is widely used (Walker et al. 1997, Tischendorf et al. 2000, Adriaensen et al. 2002, Schadt et al. 2002, Nikolakaki 2003, Mikel et al. 2010, Pino and Marull 2012, Rudnik et al. 2012). Here hub or habitat patch connectivity within a landscape matrix is evaluated by the calculation of cost function assigned to moving organisms as an effective or functional distance e.g. between the hubs within the network (Moilanen and Hanski 2001 and Adriaensen et al. 2002).

h) Methodology for the Case Studies

To delineate a multifunctional landscape network, using a method which allows considerations on movement and exchange is suggested. As a conceptual framework the widely accepted network structure of hubs and corridors is taken. But to ensure patency (low degree of dissection or obstruction) of the corridors connecting the hubs, least cost path method is adopted. To emphasize this, the approach indicated by Impedance Based Network Mapping, and as a master approach for the identification of a multifunctional landscape network, five step methodology is developed:

lay down of a multifunctionality concept

- hub identification
- impedance definition
- corridor delineation
- mapping and analysing

The result of the Impedance Based Network Mapping method is to create visibility of a spatial network structure which is able to support migratory but also resilience purposes. The resulting network map reflects multifunctional ecosystem benefits from hubs and linkages and can serve as a spatial guide for decisions on biodiversity, landscape and/or heritage conservation as well as on adaption measures.

II. Case Study I: Kurdistan Region

a) Case Study Area

The case study area “Kurdistan Region” (KR) is located between 32°57′N and 37°22′N and 41°17′E and 46°20′ E and contains all the administrative territory of “Kurdistan Region in Iraq” broaden by an extension. KR comprises an area of 48,435 km2 and its population is estimated by 6,657,277 inhabitants. The region is geographically diverse. Following the geological formations three major morphologic units - mountainous ranges (Zagros Mountain chain), foothill pediments and agricultural plains - can be identified. The topography of KR varies between 250 m and 3600 m above sea level. Topographically KR is divided into three main zones – plain, semi-mountainous and mountainous zone – in which climate varies from hot and dry plains to cooler mountainous areas.

One of the severe ecosystem changes as a human footprint consists in the fragmentation and destruction of natural forests. Human overexploitations of the natural forests, as well as shifting cultivation and uncontrolled grazing have denuded large areas of the natural forests. According to Chapman (1959) in 1957 the forest covered 60% of the mountainous region, decreasing to only 18% in 2009 (Mohamed 2011). This contributed significantly to the general decline of original forest cover in Iraq from 13% down to 2% in 2003 (Earth Trend 2010a).

Moreover there is loss of heterogeneity in agricultural landscapes. Earth Trend (2010b) reported 22,59 % decline of "Agricultural Lands Experiencing Greenness" in the period 1980 to 2003. In general the natural and managed land covers of KR have been shifted dramatically within half of a century as Fig. 2 illustrates.

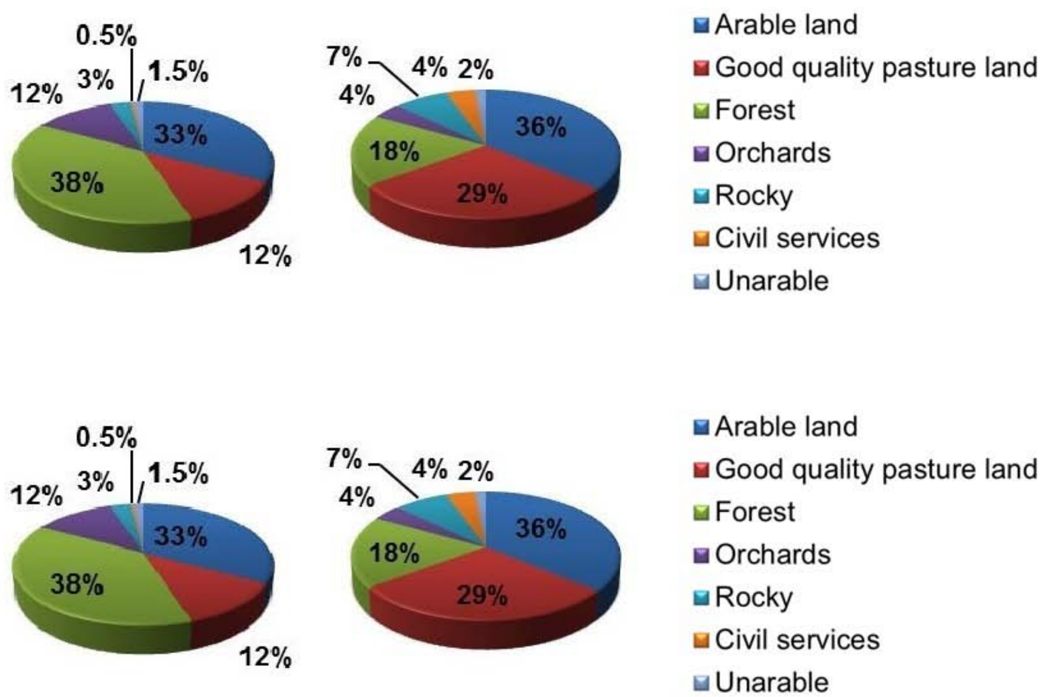


Fig. 2: Land use by type in KR for years 1947 (Chapman 1959) and 2000 (FAO 2003) Addopted from (Mohamed 2011)

The counter effect of war and political conflicts, and due to the fact that significant parts of KR is located in the mountainous area, urban development - the common expected cause of fragmentation of the biotic natural resources - was limited. However the destruction of rural landscape and natural landscape mosaic due to deliberate political decision caused fragmentation per se and due to infrastructural network development (Fig. 3).

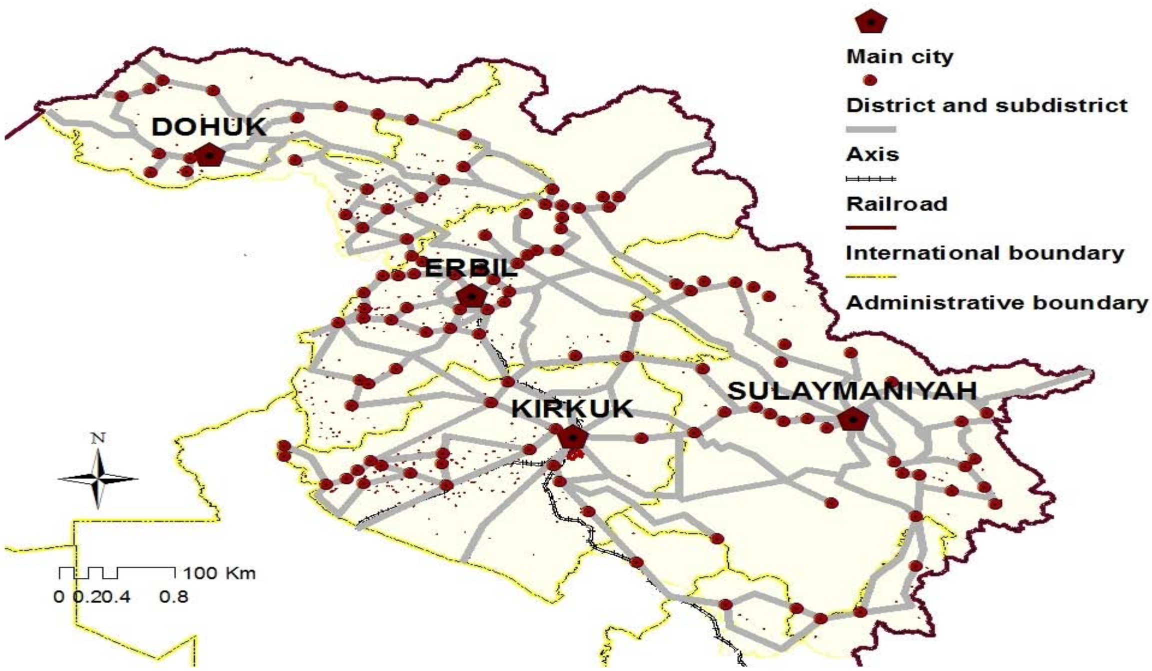


Fig. 3: Settlements, road and railroad infrastructures in the case study area KR

Compared to the whole Iraq KR is characterized rather as a rich region concerning the natural environment and in terms of the share of ecosystem services and biodiversity resources. In addition the KR is characterized as having a significant importance from the scenic landscape perspective which is intensified by a rich historic environment and cultural heritage. The historical sites are from a wide span of time starting from Middle Paleolithic period (the era of Neanderthals and cave dwelling, e.g. Shanader cave) and followed by early agricultural civilization in the plain region (e.g. 6750 BC at Jarmo) or by formal settlements (e.g. Erbil Citadel 7000 ago). This unique combination of human legacy and civilization of humankind is one of upmost important in terms of cultural heritage. Here preservation targets have to respect not only a local legacy, KR is belonging to the historic heritage of humankind as a whole being a vivid museum of civilization. The intention of the identification of landscape network for the KR is to combine this extraordinary cultural and historic importance of the region with its natural landscape potentials concerning biodiversity and scenic value.

b) Multifunctionality Concept

The development of a landscape network plan using Impedance Based Network Mapping method is highly dependent on the concept of emphasis of different ecosystem functions in addition to targets concerning biodiversity conservation. The significantly important ecosystem services, i.e. provisioning services, regulating services and cultural services, are to be maintained by a developed landscape network plan consequently. For KR biodiversity preservation, landscape heritage and historic environment conservation, scenic landscape quality and managing hydrology are identified as ecosystem services to be addressed. The developed plan aimed to identify the regional resources, by creating ecological infrastructure base map, then developing a concept for integrating and connecting these ecosystem resources spatially. It is to preserve and restore the ecological and cultural landscape diversity and its values within natural semi-natural and agricultural landscape.

The ecological network concept for maintaining biodiversity can be achieved by connecting and integration of conservation areas or areas with significant biodiversity through landscape corridors and links. Naveh (1995) demonstrates in the “green book” the importance of conservation of landscapes and environmental features, in parallel to traditional natural conservation and the species red list. Mander and et al. (2007) recommends establishing a link between biodiversity and cultural diversity to achieve ecological heterogeneity, in multi-functional landscape. Both concepts had been followed in defining corridors. Explicit spatial allocation by using the Impedance Based Mapping Method for the cores and corridors are applied at regional scale.

c) Hub Identification and Hub Buffer Zones

Benedict and McMahon (2003) define hub patches as “anchor green infrastructure networks and provide an origin or destination for wildlife and ecological processes moving to or through it”. That is why, the areas of high value of biodiversity and ecological process has been taken as targeted category for hub identification. Sensitive wildlife habitat areas can be identified mainly from Key Biodiversity Survey of Kurdistan provided by Nature Iraq (Ararat and et al. 2008). The Key Biodiversity Areas (KBAs) are defined as "sites that are large enough, or sufficiently interconnected, to support viable populations of the species to which they are important". The KBAs selection process (done by expert Richard Porter together with Bird Life International, an NGO association for nature conservation in the Middle East) uses a set of four criteria based on the presence of four categories of species for which site-scale conservation is appropriate. The criteria are (1) globally threatened species, (2) assemblages of restricted-range species, (3) congregations of species that concentrate in large numbers at particular sites during some stage in their life cycle and (4) assemblages of biome-restricted assemblages (Ararat and et al. 2008 and Ararat 2009).

In addition to the KBA Kurdistan-list, additional areas of biodiversity richness (from the KBA Marshland-list) together with concentrations of important areas for water and aquifer management are considered as a hub core (e.g. Hawija marsh which is identified by Bird Life International as a significant habitat for birds) (Mohamed 2011).

Hub buffer zones were defined around the core areas as a mitigation zone against fragmenting effects of developments on the edges of the core areas and enhancing the ecosystem services provided by the cores. Although buffer zones and its width should be designed on a case-by-case and site-by-site basis (Brown and et al. 1990 and Martino 2001) following the requirements of specific functionalities and spatial intensities, but a constant buffer zone of 1 km is suggested as an appropriate all requirements overarching neighborhood.

d) Impedance Definition

To develop a network of corridors between the hubs and to maximize the benefit in respect to multi-functionality including eco-connectivity and eco-integrity an impedance layer as a result of GIS-overlay procedures was generated. Based on a GI typology as well as mapping and analysing ecosystem resources, cultural and natural resources and landscape elements and components a set of nine indicators have been used to develop an impedance surface value covering the KR (impedance raster layer). The indicators that are identified to give input to the surface value for delaminating the corridors are considered as planning decision indicators and separated in two groups.

The ArcGIS-Toolbox utilities 'cost distance', 'least cost path' and 'corridor' are used for corridor delineation using a final impedance layer. The least cost algorithm is used as the cumulative cost calculation to reach destination cells and the location of paths and corridors having minimum cost when balancing cost for each cell crossed from the source cell to destination cell. In the application of least cost technique two main raster based layers are needed, the source layer (in which the hubs are identified) and the friction/resistance/impedance layer which is used for cost calculation. In other research applications the value of resistance grid cell layer is mostly derived from the land cover type (e.g. Adriaensen and et al. 2002) or from altitude and flow rate (Michels and et al. 2001). In the course this research the cost layers used are called "impedance layer" to emphasize that landscape connectivity is addressed as a degree to which the landscape facilitates movement. Also the impedance layer redefined to include not only land cover but also natural and cultural heritage, water and other ecosystem resources.

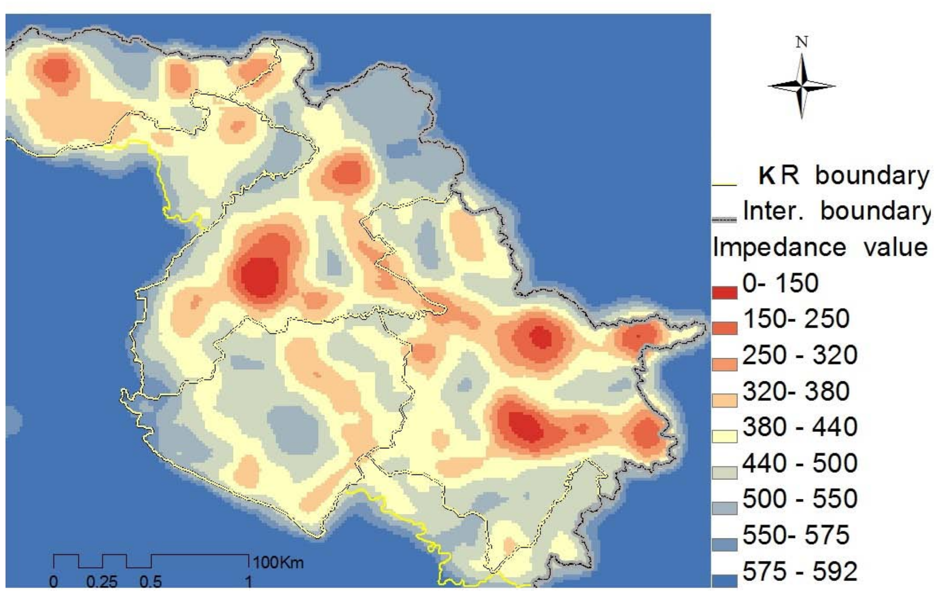
The first set A consists of six attraction-by-density indicators (Table 1). Density of these elements is considered as inversely proportional to impedance and the corridors are designed in the aim to pass through the more dense area. The second set B of attraction/avoidance-by-distance indicators has been used with the same basic principal with the difference in defining impedance by Euclidean distance. This gives surface value to the identified set of parameters based on closest proximity from the sources.

Table 1: Landscape elements leading to impedance definition

Set	Landscape Element	Effect for impedance [a]
A	Mound site [b]	Cultural heritage (–)
	Historical site	Cultural heritage (–)
	Landscape of high value	Attraction for tourism and as an ecological infrastructure (–)
	Karez [c]	Water supply and cultural heritage (–)
	Streams	Water resource management at watershed level and as an ecological infrastructure (–)
	Flood zone	Water resource management at watershed level (–)
B	River	Water resource management at watershed level and as an ecological infrastructure (–)
	Road	Anthropogenic dissection (+)
	Buildup area	Anthropogenic dissection (+)

[a] increase (+) or decrease (–), [b] artificial hill for human settlement, [c] subterranean aqueduct

Following Tomlin (1990) a cell-by-cell aggregation has been applied. Instead of using local maximum method - in which the most constraining value at a raster cell is assigned to develop the attraction/resistance surface - a compensation accepting method in which all indicators contribute to the impedance values by equal weight is applied. So for each set of identified indicators the indicators have been equally weighted summed up by using an appropriate raster algebra function in GIS (Fig. 4a,b). To combine both sets of parameters (resulting from different analytical functions and processing steps) a normalization of scales have been applied before finally overlaying the aggregations of the two sets for the impedance map shown in Fig. 4c.



(a)

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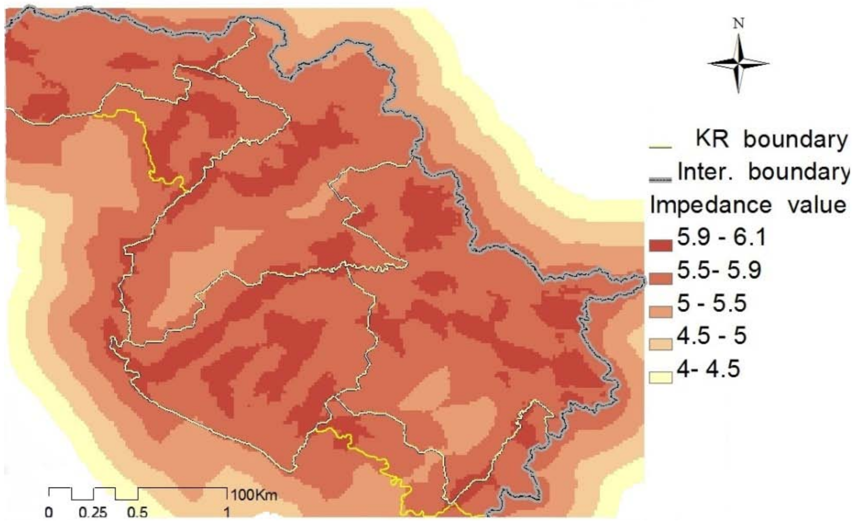
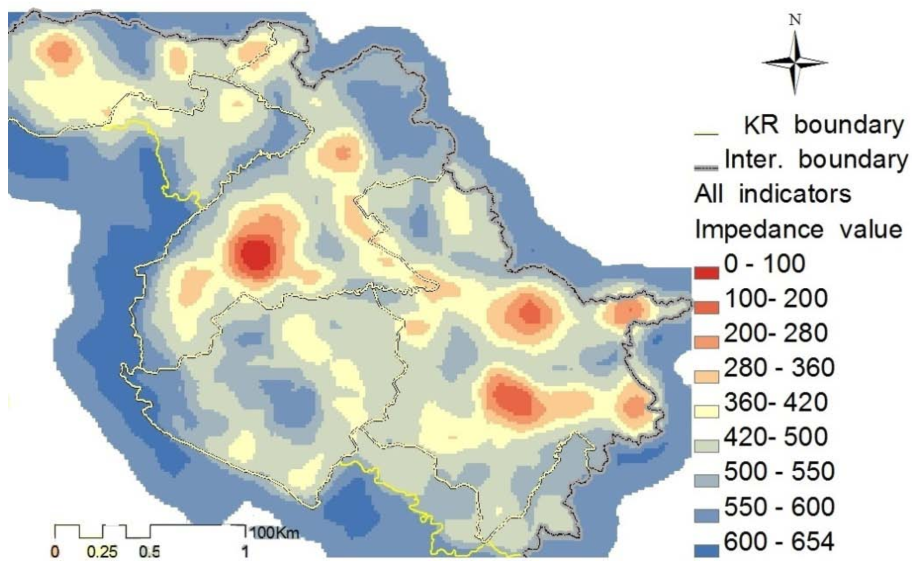


(b)



(c)

Fig. 4: Impedance map a) from set A, b) from set B and c) from overlay. Adapted from (Mohamed 2011).

e) Corridor Delineation

Different GI elements with high potential of conversation, preservation and cultural/historic/ recreational values exist in the KR and are used for a multifunctional definition of ecosystem network which respects economic feasibility and ethical responsibility. Thus corridor identification will not be exclusively bounded to wildlife movement and biodiversity conservation. To achieve a multifunctional network the corridor concept in the context here is designed to achieve the aim of conservation, preservation protection and restoration of ecosystem resources in comprehensive meaning including biodiversity and management of cultural, historic, recreational and water resources.

To identify the corridors path the impedance layer has been used as a cost raster to give weighted value for the identification between pairwise different sets of patches as source and destination (start/target). Then a threshold is set, and the accumulation of cells less than the threshold are identified as area for delineating the corridors.

f) Result and Discussion

After identifying hubs and corridors between the different hub patches multifunctional network that consist of hub, core and corridor have been developed. Fig. 5 shows the network. The corridor is identified from both the ecological infrastructure and the landscape perspective to deliver different ecosystem services, including landscape linkages (linear and non-linear), recreational routes (so called greenways) and entire ecological networks (Bennett 2006).

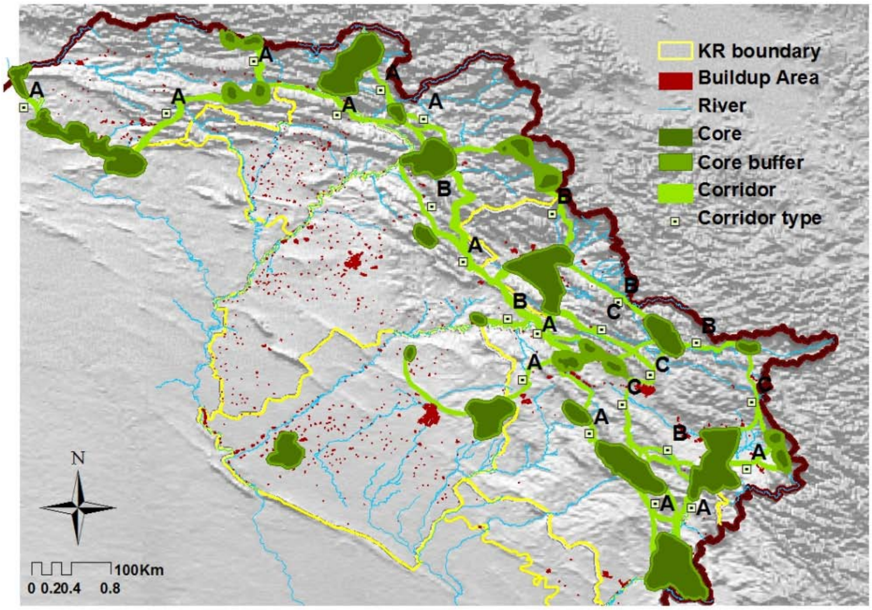


Fig. 5: Landscape network for the KR case study area that consist of hub cores and buffers, corridors and links. Adapted from (Mohamed 2011).

Although each corridor may have one or more functionalities, but the dominant function which is important to perform is identified and assigned to the corridor. For example some designed corridors are acting as a riparian buffer for the existing surface water (rivers). In Fig. 7 three main categories are identified: (A) wild life movement function, (B) Conservation function and (C) landscape function. When connecting hubs like KBA Maidan and Barzan - which have been identified as a hot spot in gap analysis for connectivity and integration (Mohamed 2011). the corridor is designed as category (A). Here wild life movement as mitigation and adaptation for climate change - particularly increase in temperature - can take place.

To validate the applicability of the Impedance Based Mapping Method and the effectiveness of identified parameters for corridor delineation and proposed network, the coincidence analysis is carried out by overlaying plan on the natural resources, land cover and natural ecosystem. A set of five main layers namely Land cover, Watershed, Karst, Soil type and Land limitation have been developed with further detailed Sub-classification. The proposed network set against each layer for analyzing the visibility. The identified corridor and core are located on areas 72% and 61% correspondently within areas presently vegetated. Also they have located on areas with soil type 82% and 71% is suitable for forestry area. The finding also suggested that the proposed plan have no salinity or low rainfall or rocky area. While watershed and Karst layer is covered with a high intensity. The delineated corridors and core hubs are covering 94% to 81 % of formally forest, agroforest or vegetated mosaics.

III. Case Study II: Baden-Württemberg

a) Case Study Area

Baden-Württemberg (BW) is a federal state of the Federal Republic of Germany situated in the southwest of Germany. The territory of BW covers 35.751 km^2 and is populated by 10,8 millions of inhabitants (BW 2015). In Baden-Württemberg we find 4 main types of landscapes. Beside the urban and suburban fabric and broad deciduous, coniferous and mixed forests, hilly and mountainous areas are covered by a more or less diverse pattern of small woods, grassland and arable land endowed with more or less densely dispersed structuring biotopes. In addition, river floodplains provide other specialized habitat.

There is a big urbanized/suburbanized area in the center and the northwestern sector of the state territory (Mannheim/ Karlsruhe/ Stuttgart/ Heilbronn) supplemented by existing and upcoming urban centers (Fig. 6). Physical planning tries to organize urban development and urban growth following a network structure of development centers and axes (Fig. 6) which also indicates the main network of dissection and fragmentation pressure for open space areas left.

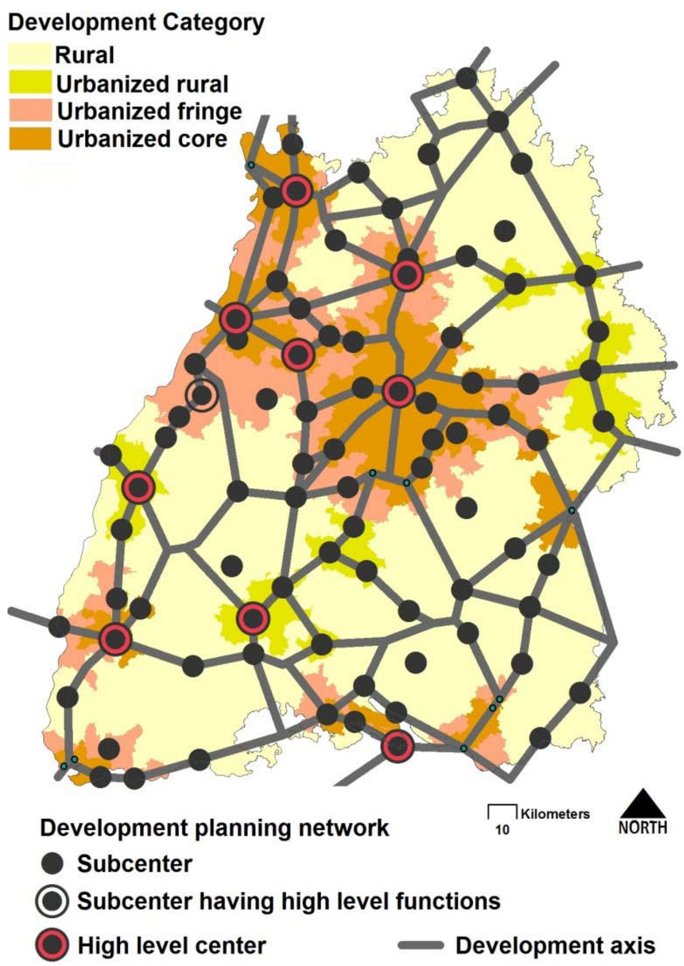


Fig. 6: Urbanized areas and development centers and axes in the state of Baden-Württemberg. Map generated from GIS data provided by State Agency LUBW according to WMBW (2002)

Jaeger et al (2007) have analyzed the temporal development of landscape dissection using the indicator Effective Meshsize. A decline of this indicator from 29 km² in the 1930s down to 13 km² in 2004 indicates a massive loss in permeability of landscapes in Baden-Württemberg. There is a concentration of this loss in the areas of high urbanization and we must state that the remaining permeable islands solely consist of the mountainous areas of the Black Forest and in the Sweabean Alb.

b) *Multifunctionality Concept*

As stated in the introduction, from a comprehensive landscape perspective there is a need to preserve natural landscape networks e.g. to establish a web of resilience against disturbance from transformations in the urbanized and urbanizing areas. Landscape networks often are defined from a single mostly bio-connectivity driven intention. But when arguing that the network should be ready to provide resilience services on a wide range of transformation impacts the definition of a landscape network must follow comprehensive principles. At the moment two of such principles are worth to follow: (1) either we have a complete survey of ecosystem services relevant for the task of the network and we then take that survey as a guiding background, or (2) we find one or a small number of universal indicators supporting the delineation of the network. For the case study of Baden-Württemberg we tried to take landscape dissection as a leading indicator, assuming that areas of low dissection by settlement and transportation infrastructures have a low anthropogenic disturbance, a high permeability and thus are universally predestined for preservation and resilience in regard to a lot of landscape functions (which has to be shown and proved).

c) *Hub Identification*

Hub identification goes back to the category of UZVR (as explained in the introduction) which is a well-established policy to preserve undisturbed open space being bigger than 100 km² in size. The borders of these units are generated by the combination of roads having a traffic volume of more than 1000 vehicles/day, railways, settlement and other anthropogenic structures. Considered as big un-dissected areas they should be preserved from further urban and transportation development. The State agency of environment (LUBW) as well as nature conservation NGOs are aware of the importance of those relicts and emphasize their contribution to biodiversity, recreation and clean air production. Fig. 7 shows the location and the spatial distribution of the units which here are considered as hubs. From the historic and recent suitabilities for settlement development their existence is linked to mountainous areas, but also to former and recent military use. Whereas in the area of the black forest woodland covers more or less completely the hubs, in the region of the Swaebean Alb they consist of hilly open landscapes mixed with forest.

d) Impedance Definition

Impedance was defined in the case study by a GIS procedure which uses the method of Effective Meshsize (meff) calculation (Jaeger 2000). Effective Meshsize measures the degree of landscape dissection by analysing a network which consists of meshes built up from settlement edges, roads and other anthropogenic linear elements which must be considered as reducing permeability and connectivity of extra-urban land. The bigger the meshes the higher meff is calculated by Eq. 1, in which the choice to calculate the square of mesh-area results from probabilistic considerations on the chance of a meeting of two individuals or the chance that a randomly fixed pathway crosses a border of a mesh.

Eq. 1

$$\boldsymbol{meff} = \left(\sum_{j=1}^{n} \boldsymbol{Aj}^2\right) / \boldsymbol{Ar}$$

Region r divided into n meshes,

- A_j denotes area of mesh j $\in \{1,\ldots,n\}$,
- A_r denotes the area of the region

To get an impedance surface indicating the local permeability in terms of the meff-concept a regular lattice of points was generated and for each point the dissection of a radial 3km-neighborhood was calculated using Eq. 1. In a second step the result of the calculation at the points in the lattice was interpolated to get a continuous surface of local permeability. This meff-surface (Fig. 7) then can be interpreted as a spatially continuous impedance layer and can be used as an input for corridor delineation.

e) Corridor Delineation

Each corridor analysis needs a couple of start/target patches. A direct solution is (1) to take each hub of the set of hubs, (2) to extent this set of start/target locations with external locations to allow that the procedure delineates corridors to touch the borders of the area of interest and then (3) to connect each hub location with the other hubs. Practice shows, that not all hubs must be included in the analysis due to some hubs being automatically included. Fig. 7 shows the selected start/target locations used in the analysis.

The delineation of corridors between the start/target locations then was done using the ArcToolbox utilities 'cost distance' and 'corridor' and by the help of an ArcMap-Extension (Lang et al. 2008). The impedance surface generated as described above was used as cost layer for the corridor definition.

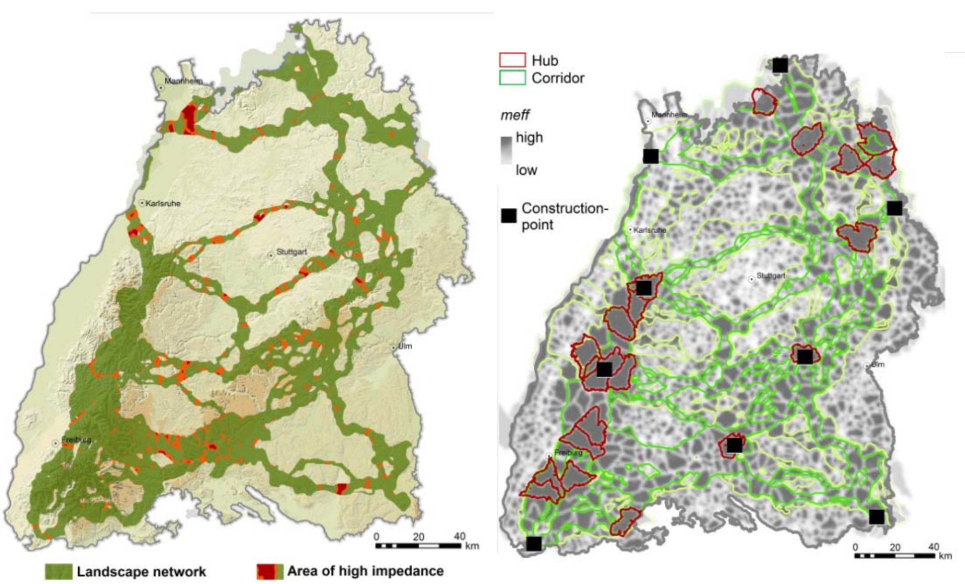


Fig. 7: Impedance surface, hubs and corridor generation points for the BW case study (left), and hot spots of obstruction (highly dissected areas / very low Effective Meshsize meff) (right) (adapted from XXX)

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f) Result and Discussion

Combining all corridor calculations and the start/target-meshes we get a system of corridors built up from relatively low dissected area connecting big un-dissected areas. We call this system of hubs and corridors "resilience network". The network indicates the location of undisturbed hubs and it gives an orientation for preserving areas which have the function of linking the hubs and being recommended to keep free from further reduction of permeability. Fig. 7 shows the result.

Fig. 7 also indicates hot spots of fragmentation inside the network, where the permeability is extremely low or blocked. These hotspots should be of high preference in the set-up of measures for rehabilitation of permeability e.g. by green bridges, traffic regulation or enhancing green infrastructures in settlements.

To qualify the landscape network we did some coincidence analysis by overlays with existing nation-wide corridor systems. The so called " Wild Cat Corridors" suggested by the NGO Friends Of The Earth (www.bund.de/wildcat) are covered very well by our corridor network (Schwarz-v.Raumer & Esswein 2010) and shows a good accordance in the Black Forest and the Swabian Alb. The habitat corridors ("Lebensraumkorridore") propagated by the German Federal Agency for Nature Conservation (Böttcher and Reck 2005) suggest three types of habitat corridors which can be compared to the network designed here: (1) The habitat network for species of forests and partly open landscapes is widely covered by the suggested network due to the coverage of big meshes by forests. (2) The habitat network for species of river valleys with humid and dry habitats cannot be considered from a conceptual point of view. (3) The habitat network for species of dry landscapes which covers the Swabian Alb is nearly congruent with our network. However in other regions (e.g. along the rivers "Murr" and "Rems") the network not existing there indicates the habitat network "Lebensraumkorridore" being highly fragmented.

A second analysis (Schwarz-v.Raumer & Esswein 2010) shows that (a) high value habitat structures can be found concentrated inside the network as well as (b) biotopes predestined for being included in a local biotope network and (c) Special Protection Areas (SPA) which are identical to bird protection areas as a part of the EU-wide natura2000 protection areas.

IV. Overall Discussion

Within rich and diverse landscape mosaics mutlifunctional resource management can be enhanced by developing multifunctional network. Up to now (even with the freshly established environmental regulations in Iraq) the connectivity is not a mentioned aspect although the fragmented landscape and isolated entities approach is proved to not be sufficient in dealing with natural and cultural ecosystem in a sustainable and resilient way. The landscape mosaics of cultural and natural resources are subject to opposing interests of economic development and nature conservation on the one hand and suffer from political conflicts on the other hand. At legislation and decision-making level, implementation of a connectivity and permeability approach is a must at both planning legislation and planning practice. A multifunctional network plan, by introducing the corridors to connect KBA and maximizing the benefit outcome by preserving the existing cultural and natural resources, is developed.

In Baden-Württemberg a revision of a significant number of ideas, proposals, guidelines and instructions concerning landscape networks must be initiated. Actually a revision of state wide development and environment plans is overdue. Besides the integration of network concepts this revision has to respect the developments in transformation research as well as the requirements of resilience in a comprehensive approach of spatial organization.

Network oriented organization is an obvious and a kind of 'natural' principle for the development of settlement and transportation infrastructure. The settlement systems spatial organization looks quite similar to nature borne phenomena (e.g. neural neuronal networks or growth patterns of fungi). Due to the advantage of settlements being concentrated and due to transportation following travel time and cost optimization a network system is a self-evident spatial organization. The question for an adequate organization of landscape arises if settlement networks get narrow or other pressures reduce spatial coherence of natural landscape. Then landscape networks as a "dual network structure" complementary to the settlement network structure has to be organized and established as a general principle in landscape preservation, as illustrated in Fig. 8. Following a methodological framework our case studies show, how - depending on the given geographical and societal framework - different construction rules can lead to such landscape networks. When following this idea different situations of interrelationship between urban hubs / landscape hubs and urban corridors / landscape corridors can be discussed based on a topological classification. Conflicting zones between corridors and transportation axes can be highlighted (Schwarz-v.Raumer & Esswein 2010) as well as distance thresholds for resilience and further development can be discussed.

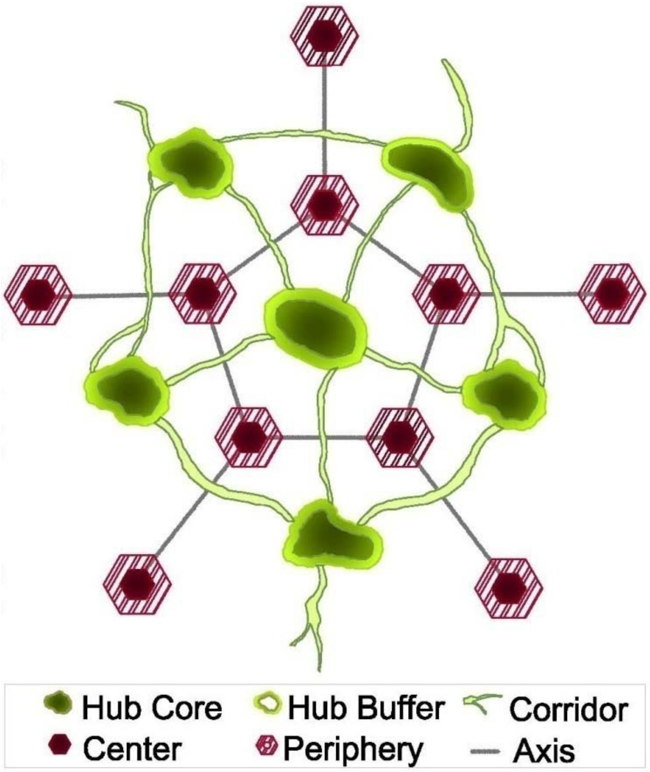

Fig. 8: A graphical diagram for thinking landscapes as dual networks

V. Conclusion

The Impedance Based Mapping Method applied is proved as very helpful method to draw a multi-functional landscape concept of ecological infrastructure and green infrastructure. It has proved to be an effective mapping method for investigating connectivity loss within ecological infrastructure in the case of BW and in developing a multifunctional network with high degree of connectivity and integrity in KR. It has been demonstrated that GIS is a very helpful tool to design multifunctional network and proposed method suggests a universal idea for integrated spatial development planning.

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Highlights

- Resilient landscape network planning by using impedance based network mapping method.
- Impedance layer includes land cover, natural and cultural heritage, water and other ecosystem resources.
- Corridor delineation contributes to achieve the aim of conservation, preservation protection and restoration of ecosystem.
- Resilience network indicates the location of undisturbed hubs and areas with linking functionality to be preserved and kept from dissection effects.
- Landscape networks as a “dual network structure” complementary to the settlement network structure.

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Rural Inhabitants Participation in Infrastructure Development in Niger Delta, Nigeria: Separating the Wheat from the Chaff

By Okwakpam, Ikechi Omenuihu
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Abstract- The benefit of infrastructure services has been inadvertently ripped apart by non inclusion of the rural inhabitants in the development strategy. The government in many instances has been largely unsuccessful in providing independently the much needed and envisioned goal of infrastructure development. Therefore, the paper examines the extent of participation and level of involvement of the rural inhabitants on physical infrastructure development in the niger delta region of Nigeria. The study used mainly secondary source of information and, adopted content analysis technique. From the findings there exists, ostensibly, missing link on government policy. It is evidenced that the Government infrastructural rural development policy is increasingly less concern with the actual content and participation of the users themselves (rural population that will benefit from the project). The paper identifies clear frustrating approach, amongst which are; lack of rural values, imprecise social objectives, uncoordinated and unguided inputs. It recommends broad-based and inclusive development frameworks, having the inhabitants inputs guided and coordinated by representatives of the area, and a creative "bottom up" planning approach viewed as mass – oriented. This will more likely deliver better results, combined local feedbacks and evaluation by establishing a scene of collaboration with the indigenous rural population.

Keywords: development, infrastructure, niger delta, participation, rural.

GJHSS-B Classification: *FOR Code: 040699*

RURALINHABITANTSPARTICIPATIONININFRASTRUCTUREDEVELOPMENTINNIGERDELTANIGERIASEPARATINGTHEWHEATFROMTHECHAFF

Strictly as per the compliance and regulations of:

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Keywords: development, infrastructure, niger delta, participation, rural.

I. Introduction

Stretching across the national development plan of Nigeria, the cardinal thrust of infrastructure development have been rise in the standard of living, favourable changes in the way of life of the people concerned and their needs. This indeed, suppose to have started with providing basic needs of the people, including the capacity to make their own decisions, and participating in decisions that affect their lives. In other word, rural services suppose to have institutions and individuals through whom it can function, have goals that are adjusted as implementation proceeds, in line with experience and the changing conceptions of the groups and sponsors concerned (Leye 1993). Basically, the functionality is to provide suitable development in rural area.

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Often time development programme are carried out on behalf of the people by the government institutions believing that it knows everything concerning rural population and consider the rural population not yet ripe to participate in the management of their own affairs. The provision of infrastructure are so often the responsibility of the different agencies or ministries: some provided by local government; state government; national (federal) government; International oil companies; Faith base organization; Nongovernmental organizations. There is rarely the needed coordination between them. Rural population is not taken into consideration the existence of its peculiar problem and commitment of the appropriate institutions to effective rural services. The provision of rural infrastructure was not based on participatory approach, where infrastructural services is heightened on sustainability and self-reliance manner and, which aims for the realization of social and institutional improvement in the community. It is most important to have information on current state of needs/demands of the rural inhabitants that aid the people in choosing their own development path and the activities in which they would participate. It is on this note that the paper examines the extent of indigenous rural involvement in participation on physical infrastructure development in rural Communities of Niger delta region of Nigeria.

II. Conceptual Explanations

a) *Infrastructure Development*

The importance of physical infrastructure development such as road, portable water, electricity, health, education, housing, transportation and communication in the overall development of rural area cannot be underplayed. Infrastructure development is a large-scale system of services and facility of a country or region that are necessary for economic activities (Ajakaieye, 2003). It is an umbrella term for many activities referred as social overhead capital and, most often regarded as one of the key levers of rural development, which attempts to utilize in a coordinated and deliberate way the information and resources available in the area.

Infrastructure development is essential in improving and enhancing the quality of life of the rural inhabitants. No doubt, it brings about enduring changes with enhanced standard of living that translates a process by which a set of technical, social, cultural and institutional measures are implemented for the inhabitants of the area with the aim of improving socio-economic conditions of the populace. In a rural setting, development of infrastructure is important to promote growth and high economic rates of return to investment (Tarique, 2008). Beyond economic and social indicators, it transient mainly with people's capacity in a defined area over defined period to induce and manage positive change; that is to predict, plan, understand, and monitor change, and reduce or eliminate unwanted or unwarranted change.

According to Leye (1993) the basic objective of rural development is ensuring improvement in quality of life in the rural areas by providing basic infrastructural facilities. Improving living standard revolve around physical development (telecommunication, transport and water supply) and serve as the wheel and, social infrastructure (encompassing health and education) viewed as the driving force of rural development. United Nations' Food and Agriculture Organization had observed the kind of rural participation practiced in developing nations as voluntary contribution of people infrastructure development, but without taking part in decision making. In the same vein Ijere (1990) postulated the underlying principles of rural development as: 'total community involvement; utilization of cultural values and practices of the people; policy commitment to the philosophy of rural inhabitants for the improvement of the area.' It is important taking the need and opinion of rural residents into account as much as possible in the formulation and implementation of developmental policy.

b) The Rural inhabitants

The term 'Rural inhabitants' has often be referred by most Scholars as those who dwell outside the densely built-up environment of towns, cities and sub-urban villages and engage in primary as well as rudimentary forms of secondary and tertiary activities. Sometimes the criteria for classification are based on political, population and administrative consideration. In recent time, demographic and socio-economic criteria are mostly used to define rural area. It is calculated as the difference between total population and urban population (World Bank, 2010). In most Africa countries, active engagement in economic activities of subsistent farming, grazing, lumbering, forestry, hunting, fishing and mining is considered rural activities, with utmost insecure livelihood; a small scaled area with low density. Rural community in Nigeria is a population of less than 20,000, constitute over 80 percent of over 170 million total population of Nigeria (National Population Commission, 2006). In some countries, it specifies area with not more than 2,500 inhabitants outside urbanized areas (The Hindu, 2014).

The Niger delta rural settlement is an area which contains all or most of the elements of a common life and, most often, predominantly distinguished by paucity of social services, infrastructures, adequate institutional and administrative frameworks for the provision of basic utilities such as water, electricity, good (tarred) road, leading to poor standard of living. Rural Niger delta is often characterized by dominant economic activity of farming, fishing, craft and informal economy that form the foundation of the economic development, which provide livelihood for the nation. The population comprises the teeming mass of under privileged illiterate and poverty stricken population with no knowledge of their rights and privilege and who, most times, are not privileged to participate in development issue that affect their quality of life (Obinna 2008). Some Scholars portrayed the rural Niger delta as the population of the deprived group, suffering from cultural, economic, political, and social deprivations.

c) Participation

According to a German development agency, participation is a ''co determination and power sharing which entails involvement in development processes.'' It entails social development in which people as subjects in their own environment seek out ways to meet their collective needs and expectations and to overcome their common problems. It is not a dichotomous entity but rather, a continuum based on the degree of people's involvement and engagement of people in activities within the communities. As stated by Fung (2006) Indigenous involvement in infrastructure development seeks to get things done in a representative manner based on a fixed quantifiable development goal and ensures that development process is much more valued by the people. The process ensures that the relevant agencies is synthesized in a way that addresses parties concerned, and that those who may benefit from the infrastructure development are sufficiently well informed and meaningfully involved in the development process. The participation process develops people's capacities or abilities to recognize and improve their inherent potential, and provides them with opportunities to influence and share power, i.e. power to decide and to gain some control over their lives (Silverman, 2005). But, the weak organizational capacity that characterized rural area makes it difficult for the indigenous people to fully participate in the process of development. The People interest is not (stakeholders) influenced and does not share control over development initiatives and the decisions and resources that affect them.

One of the cardinal policy thrust of the 'African Development Board (ADB)' is to encourage and expresses the needs and interest of the target population by engaging the rural inhabitants in initiating design for their benefit in the hope that infrastructure development will be more sustainable. This engages rural inhabitants in initiating design for their benefit and achieves greater individual fulfillment, personal development, self-awareness, some immediate satisfaction and essential for long lasting role in promoting quality of life. Participation is an indispensible element in the promotion of infrastructure development and therefore capacity to participate in infrastructure development must directly involve the people who share, enhance, monitor, analyze and evaluate their knowledge of life and conditions to plan and act.

III. Institutional Interventions in Infrastructure Service Development in the Niger Delta

The discovery of Oil in the Niger Delta region of Nigeria is a strategic resource that powers the economy of Nigeria. With over 600 Oil fields, revenue earned from the region in the past 50 years is estimated at over $600 billion. It has contributed immensely to the overall socio economic development of the Nigerian state (Watts 2007). Despite this stupendous wealth and its contribution to the Nation's economy, the continued exploration of oil and its production in commercial quantities have created problem of ecological degradation thereby affecting the peoples' conditions of living, constricting its livelihoods and local economy. Evidenced by some scholars, in the past 50 years, the trend has placed infrastructure development in Niger delta in dire state and has a history of non-performing government infrastructure development institutions. Very little of the oil revenues have been ploughed back for the development of the region. The lives of the people have turned into a harbinger of misery, poverty and anguish.

There have been concerns over the years by Policy makers to employ rural infrastructural development as a strategy to redress the problems of rural areas, especially the Niger Delta region of Nigeria. Its challenges lied in the many contentious policy initiatives by involving provision of rural infrastructure services to address the problems of the Niger Delta, which date back from 1958, when Henry Willink's Commission identified the region as being poor, backward and neglected. Emphasizing on Willink's report the British Government had proposed that the Niger Delta be declared "A Special Federal Territory" for focused sustainable development. The idea was to create opportunity and assume best strategy for the development of the Niger delta region (Willink, Hadow, Mason and Shearer, 1958). The 'Niger Delta Development Board (NDDB)' was then created, to carter for the unique developmental needs of the region (Igwe and Adeyemo, 2008). This tried to change in a radical way the nature of relationship between the people and the government. The scheme was short lived and had lacked the indigenous participation and hence did not satisfy the development need of the people. Also, the scheme failed to achieve any desirable results due to structural defects, fairness and justice in revenue allocation (Olowononi, 1998). The situation gave rise to frustration that had led to the establishment of Niger-Delta River Basin Development Authority (NDBDA) in 1972. Although the policy thrust was aimed at addressing ecological problems in the deprived rural areas of the region, the institution was also to serve as a veritable means of sustainable infrastructural development in Niger Delta. Again, this institution was bedeviled with administrative and political scheming and very much inadequate for the massive challenges it had to contend with. This acted as a setback in their operations and not much was achieved before it was replaced to defunct Oil Mineral Producing Areas Development Commission (OMPADEC) in 1993. Considering the magnitude objectives and functions of OMPADEC, it is obvious that the Commission did not achieve much, therefore was short lived and supplanted to Niger Delta Development Commission in 2000, with more responsibilities amongst other things to cushion the effect of grinding poverty and acute infrastructural deprivation in the Niger Delta. Regrettably, this body is witnessing failure due in part to corruption, poor governance and lack of accountability.

Also, there are plethora and deliberate policies from Federal, State and Local governments, respectively, for the development of the rural areas. For example, the Ministry of Niger Delta was created in 2008 as a bastion of the region's development. The Ministry as one of its primary responsibility is saddled with coordinating and making efforts to tackle the challenges of infrastructural development in the region. The existing Niger Delta Development Commission (NDDC) is now a parastatal under the Ministry. Past administration in 1986, created 'Directorate of Food, Road and Rural Infrastructure (DEFFRI)', which among other objectives was charged with the responsibility of working for the steady development of the rural areas. Emphasis was on solving the basic needs of the entire population of the region through increased production, comprehensive planning process, and active involvement of the population (Obinna, 2008). Even though DEFRRI contributed to socio-economic development of the region, it lacked proper planning and consequently resulted to, inefficiency, lack of accountability and transparency in service delivery. DEFRRI failed as an integrated rural development (IRD) programmes. Indeed, the evidence clearly shows that governments have been largely unsuccessful in providing independently the much needed and envisioned goal of infrastructure development.

IV. Situational Analysis of Participation in Infrastructure Development

The infrastructure development surprisingly in the area, in many occasions, does not have bearings to the needs of the target population. It is noted that most times, the rural inhabitants were not adequately consulted prior to the implementation of projects. Continuity in the implementation of development policies has been problematic. Appropriate functional institutions and managerial capacity to address this problem is lacking. Most of the Projects were not implemented on a self sustaining basis and completely left out and abandoned. There is a missing link on how and by whom were the infrastructural development plan formulated and the basis of which concerns. There exists a sharp contrast between policy formulation and its implementation, thereby placing little value which fails to take account of rural needs and necessities.

The promise of infrastructure services inadvertently ripped apart by non inclusion of the local participation in the development strategy leading to disappointment and disillusionment. Most of the projects are seen as an end rather than a means and serve selfish interest of the proponent rather than those of the rural inhabitants who suppose to benefit from the project. This implies that rural infrastructure strategy is not centered essentially on altruistic reasons for improvement of the rural communities, a significant view that infrastructure development has not brought automatic improvement in the standard of living of the people. The unexpected consequences and contradiction about the way these projects are implemented show a frequent reflection of a mode and a value system which wholly or partially at variance with indigenous rural expectation.

This frustrating condition to failure emanates from lack of philosophical base, lack of cohesive identity, inadequate community participation, lack of grassroots planning among other problems. At one end of the spectrum, the peoples participation is non obligatory and often not community oriented. It is not surprising that the plan targets are never realized, and the resultant effect has become more hardship and poor standard of living amongst the indigenous dwellers. This ultimately alienates the inhabitants accustomed in many cases to have to take decision about its fate. Ostensibly, it negates the intended strategies of infrastructure development. Infrastructure development is well achieved when coordinated within the neighbourhood or the community and indigenous participation.

According to Yazd (2007) lack of village satisfaction and participation, lack of attention to rural values and the absence of rural infrastructure are the most important drawbacks to the rural areas in Nigeria. Scholars have also listed a number of factors contributing to rural infrastructure frustration to include: Poor finance appropriated for development; inadequate manpower in effecting plans for rural development; uncoordinated plans to reflect the target objective; imprecise social objectives and hence poor guides for plan execution. Ideally, the direct involvement of the people does not only help to sustain the life of the infrastructure provided but extends the peoples' involvement in creating or establishing other new infrastructure which takes into account the ability of the rural population to participate in initiative activities by government with the support to maintain them in self-sustaining manner.

V. The Implications

The process of participation in infrastructural services is the part of the process of building effective and responsive participatory institutions related to local needs and popular demands. It is disappointing that the Government infrastructural rural development policy is increasingly less concern with the actual content and participation of the users themselves (rural population that will benefit from the project). The hiatus resignation, mismanagement and the unrealistic expectation or wrong assumptions at the outset do not always take account of local conceptions and its various functions. The peoples' efforts are not united with those of governmental authorities to improve the living conditions of the community. Presumably, this lies behind many projects failure. In general reflection, it is obvious however, that the nature of understanding of the inhabitants' participation is so often very different from that understood by government agencies. For it means participation in determining and, control, full involvement to implementation of infrastructure services.

An essential prerequisite for meaningful rural infrastructural services depend to a large extent on participation of the people that will benefit from such development. Perception, rightly or wrongly of infrastructure development as a process that change the quality of lives and also bridge the gap between deprivation and development in rural area is lacking. A Mexican Economist, Gustavo Estevan reaffirm that "development for the overwhelming majority always means the progressive modernization of their poverty." Without mutuality and understanding of the target population, development is little more than a rhetorical device. In other words, development should form rural decisions and implemented inform of participatory democracy and oriented towards the accomplishment of specific tasks An indispensable steps towards achieving this are by creating and widening opportunities for rural inhabitants to realize full potential through education, share in decision and action which affect their lives, increase rural output, create employment opportunities and root out fundamental or extreme causes of ignorance and exclusion in decision making. Giving the rural inhabitants access to information and know how can make such level of participation more effective (Hardoy and Satterthwaite, 1986). Developments that do not spring from this perception of the target population are more or less artificial and weaken the imaginative and creative capacity of the people.

VI. Conclusion / Recommendations

This paper has considered the involvement of government and the rural inhabitants' participation in the provision of rural infrastructure. It has evidenced that for the past 50 years; infrastructure development in rural Niger delta has been in dire state and has a history of non-performance. Most of the infrastructure development is not centered essentially for the improvement of the quality of life of the people. There is little value which fails to take account of rural needs and necessities. The promise of infrastructure services inadvertently is ripped apart by non inclusion of the rural inhabitants in the development strategy. The paper therefore concludes, that infrastructure development activities should involve the inhabitants' participation in initiating, deciding, planning, implementing and managing the infrastructure development activities by having their inputs guided and coordinated by representative of the enclave. This will make it more affordable for the inhabitants; operate, maintain, and own up responsibility and ownership of the infrastructure in their enclave. This demonstrates the finest accomplishments on how the inhabitants can participation in the success of rural infrastructure development.

There is need in setting up of mechanisms that reflect people's needs and desires and allows the rural people to reap more of development returns. The use of participatory research approach is important. Through Broad- based and inclusive development frameworks would more likely deliver better results, combined local feedbacks and evaluation by establishing a scene of collaboration with the indigenous rural population.

Obvious need to prioritize large scale infrastructure project is vital. This will ostensibly deliver a system needed to reduce the cost of rural infrastructural investment and to ensure smooth operation and maintenance by establishing a suitable institutional arrangement.

The top-down approach to planning is elite-oriented, performed mainly for their benefit. There should be a creative "bottom up" planning approach viewed as mass – oriented. This will warrant meaningful participation by involving a range of stakeholders from the outset, and by building capacity at the grassroots.

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Chiefdom Ecodynamics and Muisca Cosmology in the Valley of Leiva, Highland Colombia

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Abstract- The mysterious monoliths of El Infiernito, the Stonehenge of Colombia, have been the subject of much speculation and fanciful interpretation for over four centuries. Not until recently, however, has systematic archaeological investigation identified El Infiernito as an astronomical-meteorological observatory of the ancient Muisca culture. Modern surveys have begun to reconstruct the settlement history of the Leiva Valley, but little is known about the actual chiefdom community (ranked kinship society) for the stone observatory or how the it related to other communities in the region. Argued to have functioned as a calendar monument recording solar cycles, celestial alignments, and forecasting weather, many alternative interpretations are often uncritically accepted and fuel speculation for a local tourist industry as well as pseudoscientific fantasy. No serious study has attempted to ascertain if these monuments connect to anything tangible on the natural and cultural landscapes such as actual water features and specific celestial events. In an environment where effective rainfall is often insufficient or inconveniently timed for farming and alluvial farmland subject to intense erosion caused by periodic drought and flooding, the cosmological importance of fertility both agricultural and human tied to vital water sources and beneficial rainfall must have been of primary concern to Muisca leaders. A tangible response by a chiefly elite to such unpredictable conditions would include engineering a hydraulic landscape linked to intangible religious cosmology embodied in central stone monuments such as the monolithic observatory, temple structures, and artistic depictions of fertility.

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Abstract- The mysterious monoliths of El Infiernito, the Stonehenge of Colombia, have been the subject of much speculation and fanciful interpretation for over four centuries. Not until recently, however, has systematic archaeological investigation identified El Infiernito as an astronomical-meteorological observatory of the ancient Muisca culture. Modern surveys have begun to reconstruct the settlement history of the Leiva Valley, but little is known about the actual chiefdom community (ranked kinship society) for the stone observatory or how the it related to other communities in the region. Argued to have functioned as a calendar monument recording solar cycles, celestial alignments, and forecasting weather, many alternative interpretations are often uncritically accepted and fuel speculation for a local tourist industry as well as pseudoscientific fantasy. No serious study has attempted to ascertain if these monuments connect to anything tangible on the natural and cultural landscapes such as actual water features and specific celestial events. In an environment where effective rainfall is often insufficient or inconveniently timed for farming and alluvial farmland subject to intense erosion caused by periodic drought and flooding, the cosmological importance of fertility both agricultural and human tied to vital water sources and beneficial rainfall must have been of primary concern to Muisca leaders. A tangible response by a chiefly elite to such unpredictable conditions would include engineering a hydraulic landscape linked to intangible religious cosmology embodied in central stone monuments such as the monolithic observatory, temple structures, and artistic depictions of fertility.

This report discusses the subsistence and ritual roles of water at El Infiernito based on recent climate change and human ecodynamic (socio-ecological dynamics of coupled human and natural systems) research. Recently, an engineered hydraulic landscape consisting of irrigation canals, check dams and drainage conduits, as well as potential raised fields has been identified on the upland slopes and along the Rio Leyva alluvium near El Infiernito; pre-Hispanic canals and raised fields in this area were reported to be still in use in 16th century. In addition, a easy-west double row of stone columns (the observatory) diagonally aligned with the winter solstice and specific water fissures form the nascent waters of the Rio Leyva below the Cerro Santo looming behind the Colonial town of Villa de Leyva. Reconnaissance survey along these mountain arroyos revealed water pools, megalithic terrace tiers for a hilltop platform, and shaped monolithic stones adjacent to the confluence of mountain stream channels and the helio-elliptical rising of the winter solstice. Importantly, associated with the terrace platform are unique and finely carved Muisca stone portrait statues showing mythical figures emphasizing themes of fertility recalling the Legend of Iguaque, a myth of cosmic ontogeny and ancestral origin. These preliminary data strongly suggest that water sources, solar cycles, and rites of fertility were linked to the astronomical-meteorological observatory at El Infiernito and an important new highland water temple.

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I. Background

In the Leiva Valley, 120 km northeast of Bogotá, El Infiernito and its stone monuments consist of rows of aligned columns as well as dozens of phallus-like monoliths alleged symbols of fertility standing up to 4.5 m tall (Figures 1 and 2). The latter surround a dolomite slab tomb which is reported to have contained the remains of high status individuals (Silva 1983). Survey suggest that El Infiernito was the monumental center of a large town for a chiefdom by the 12th century AD if not earlier (Langebaek 201; Fajado 2011; Salge 2007). The astronomical and phallus cult interpretations of the various stone monuments remain perplexing because so little is known about the surrounding community.

The Leiva Valley is an altiplano region populated with Muisca chiefdoms along river floodplains and upland mountains between 2,000 m to 3,200 m (Langebaek 1995, 2001). Climate classification is *tierra frio* except for desert páramo found above 3,500 m. A dual rainy season occurs from March to June and October to November with intervening dry seasons; evidence for past valley erosion is intense. Overall, the river floodplain adjoining El Infiernito averages less than 1,000 mm of rainfall per year, though evapotransporation is nearly as high, but significant annual variation in precipitation throughout the valley is based upon geography, elevation, and major meteorological events such as the Southern Oscillation and its El Niño and La Niña Cycles (ENSO). The southernmost Leiva Valley is more arid extending into the Candaleria Desert. In addition, several major uplands rivers including the Rio Leyva flow near Muisca settlements, including the former chiefdom of Zaquencipá at El Infiernito (Falchetti 1975; Salamanca 2000; Henderson and Ostler 2005).

El Infiernito (2,075 m), also known as the archeological park of Monquirá, is located 4 km west of the Colonial town of Villa de Leyva. Monquirá was the first Spanish settlement in the Leiva Valley founded in 1556 later moved to Villa de Leyva in 1572. Famous for its carved stone monuments (*menhires*), especially two rows each with 54 columns aligned with the vernal equinox, is the astronomical-meteorological

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observatory. The site is dated between 700 and 1200 AD (Langebaek 2001:28), though a chiefdom community headed by a hereditary elite remained active into colonial times. Recent survey has documented the presence of a Herrera Phase (700-1000 AD) farming community when the first monoliths may have been erected (Botiva 1989; Langebaek 1995). Subsequent Early Muisca communities (1000-1200 AD), credited with constructing the "so-called" observatory, were concentrated in larger settlements that saw the formation of chiefdom leadership organization. Late Muisca (1200-1600 AD) occupations became progressively larger (Salge 2007) and more complex. In some highland regions Muisca chiefdoms were becoming centralized resulting in increased population distribution with nucleated settlements supported by intensified agriculture, interregional trade (salt, ceramics, gold, and textiles) organized warfare, and craft specialization; mummification of certain high-status individuals became a standard elite mortuary practice (Boada 1998, 2000). Before the Spanish Conquest, the Muisca at Tunja and Bogotá were ruled by powerful paramount chiefs who were becoming politically and perhaps economically stratified absorbing many regional communities into more complex forms of sociopolitical organization (Broadbent 1964; Londoño 1985).

Maize (*aba*) was the most important subsistence crop among the Muisca, though potatoes (*yomsa*) were also widely grown at higher elevations. Environmental conditions and an 8-month maturation rate for maize limited annual production to usually one crop and an average of about 2,000 kg per ha on the best farm lands, though irrigated agriculture on river alluvium was probably more productive. Production losses due to vermin and spoilage can be up to 30% even in a good year, and traditional maize varieties (*pollo*) used by the ancient Muisca had much smaller ears than today's hybrid varieties (Mangelsdorf 1974; Langebaek 1987; Smith 1988; Cardenas 2002). Drought, especially in the Leiva Valley, was and still is a constant problem and any rapid climate change effecting rainfall by reducing or swelling river levels (flooding) would have negatively impacted the production of maize as well as all crops. Such unpredictable climatic conditions arguably inspired water management strategies such as storage, irrigation, and raised field construction (artificially elevated planting surfaces).

Our contribution to site of El Infiernito is the newly discovered archaeological evidence for intensive agriculture and water management (Smyth et al. in press). Reconnaissance identified hydraulic works and evidence for major erosion events potentially related to rapid climate change, i.e., significant droughts and/or major flooding episodes. The Loma Carrera (Figure 3a), an upland area, contains a natural perennial spring (Cañada las Peñas) situated above a carboniferous shale deposit that produces hydrostatic surface water that empties into the Rio Leyva. Near the spring are two possible anthropogenic ovoid pools reminiscent of the ceremonial baths or "lavapatas" at the Alta Magdalena site of San Agustín in southern Huila (Duque Gomez 1964; Drennan 1995). Seasonal drainage was captured by a catchment surface and stone conduit that connect to a double alignment of upright megalithic boulders above a cross-channel boulder wall (Figure 3b). These hydraulic features are seemingly part of a reservoir and check dam system designed to collect and divert runoff water for irrigation agriculture.

Trenching along the Rio Leyva floodplain revealed that the current topsoil has little soil development but a topsoil buried by 175 cm showed greater development (below) suggesting major past flooding erosion and flooding events. Deeper cores indicated similar lower sequences, which showed evidence of more than one such cycle of erosion (Beach 2015; Beach et al. 2013; Smyth et al. in press; Wells et al. 2015). To combat flooding the Muisca may have built raised fields along river alluvium like those documented along the Rio Bogotá near the town of Funzá (Kruschek 2003) and elsewhere on the Sabana de Bogotá (Broadbent 1968; Boada 2006, 2007). Early Colonial sources from the Valley of Zaquenzipá (Leiva) clearly indicate that the Muisca had practiced raised field agriculture and canal irrigation long before European Contact, and that Prehispanic hydraulic features were still being used in the 16th century (Restrepo 1895; Mora Pacheco 2011, 2012, 2015; Langebaek 2013).

Muisca cosmology embodied a religious philosophy of the natural environment centered around astral deities of earth and sky governing forces believed to directly influence human affairs (Ingativa 2012). A class of priests centered on the cult of the sun but ritual offerings and ceremonies concerned many deities including those related to water and fertility. Offerings and sometimes mummies were placed at caves, hilltops, woods, and lakes and temples were erected at sacred places populated with idols such as the large wooden Sun Temple of Suamox looted and burned by Spanish Conquerors in September of 1537 and reconstructed in 1992 (Figure 4). Temple sites were places of religious pilgrimage, offerings, and ritual performance especially on days of special importance such as the Winter Solstice, considered by the Muisca to be a sacred time marking the end of the solar year and the start of a new agricultural season which were closely associated with human fertility enshrined in the Legend of Iguaque.

The legend revolves around several alpine lakes (Iguaque) sacred to the Muisca and not far from the Leyva terrace platform (Figure 5). According to legend, mankind was born when the mother goddess Bachué (the one with naked breasts) emerged from one of these lakes with the boy Iguaque in her arms. When the boy came of age, they married and their offspring populated the Earth. Finally, Bachué and Iguaque disappeared into the lake after being transformed into the bodies of snakes, where they are believed to still reside today.

II. The Observatory

The stone monoliths at Infiernito (little Inferno) have been the subject of speculation since the earliest Spanish missionaries maligned them as works of the devil because of their alleged associations with controversial Muisca rituals and orgiastic ceremonies, and perhaps most significantly, the native refusal to adopt Spanish Catholicism (Simón 1625). Among the first archaeological expeditions detailing the various stone columns occurred in 1846 (Zerda 1972). Shortly thereafter, Juaquin Acosta wrote a new appraisal of the site dismissing prior claims of any 'lost civilization' responsible for erecting the monoliths (Acosta 1850), while others began to argue correctly that *chibcha* speaking (Muisca) native peoples were the actual builders (Ancizar 1984). As archaeology became a formal discipline in Colombia, studies began to focus on classification of the stones as well as associated artifacts and human remains (Restrepo 1972; Saenz 1922; Triana 1922), though their excavations and analyses were not congruent with modern standards.

The most important recent study of the observatory was undertaken by Eliécer Silva Celis (1981) who excavated an area 38.5 m east-west by 16 m north-south and 1.5 m deep called the Campo Sagrado del Norte (Figure 2). Within this context, he uncovered a row of 26 finely carved cylindrical pillars equally spaced following the meridian each with a height of 2 m and diameter of .35 m--20 additional columns were reconstructed. A parallel southern row of 54 columns was completely restored without any stones found *in situ* but repositioned based upon the remains of broken column's debitage in association, the finding historic metal tools used to remove stones, worked shell cached by the Muisca at the foot of each column, details of associated soils (color, texture, hardness, compaction, etc.), calculations of inter-columnar spaces, as well as the incorporation of information from written accounts of travelers and visitors since the mid 19th century (Silva 1986:49-52). Unfortunately, few statistical and few graphical presentations were published or reported documenting critical context and association information from the excavations. Centered between the aligned stone rows was an alleged 5 m tall upright column functioning as a firmament to measure the height of the sun and presumably other celestial movements. Four meters south is the Campo Sagrado de Sur composed of 2 rows of four ovoid columns (Moncada 1979) whose function remains unexplained.

Dating of the observatory was based on three published radiocarbon assays recovered from excavations (2,180+/-140, 2,490+/-195, 2,880 +/-95 BP uncorrected) controversially placing the site to the 2nd and 9th centuries before Christ. However, there are two problems with these dating results. First, there are no descriptions of the contexts of association for the carbon samples except for vague references to animal bones and maize remains (Silva 1981:13). Second, the Instituto de Asuntos Nucleares, the laboratory where these C-14 samples were analyzed, has a reputation for providing inaccurate results (Langebeak 2001:28). Ceramic classification at Infiernito, conversely, dates the site to no earlier than 800 AD.

Two parallel rows of columns on the vernal equinox have a true azimuth of 91° and point east towards the Cerro Morro Negro (Morales 2009). The columns do not precisely align with the Laguna de Iguaque on the equinox as has been previously claimed (cf., Reichel-Dolmatoff 1982; Silva 1981). Importantly, a diagonal azimuth of approximately 113° measured from the westernmost column of the north row, passes through the alleged center column, continues to the easternmost column of the south row, and ultimately aligns within one degree of the true helio-elliptical rising of the winter solstice (Figures 6a-b) This significant alignment cannot be coincidental because it also corresponds to mountain fissures and streams within the Cerro Santo behind Villa de Leyva where the nascent waters of the Rio Leyva flow by El Infiernito some 5 km to the west of the Terrace Platform (Figures 7a-b). These alignments suggest that Infiernito was a solar observatory focused on water and human agricultural fertility, and not just a calendrical monument. The spatial connection between the water mountain and a terrace platform support the observation that the latter served as a water temple.

III. The Terrace Platform

A significant new Muisca site closely related to the Infiernito observatory emphasizes the vital interrelationships between water and fertility in the Leiva Valley. A terrace platform containing Prehispanic to Early Colonial Muisca surface ceramics, retaining wall stonework, large shaped megaliths, and the remains of megalithic tiers or staircase is located in the mountains behind Villa de Leyva. This possible Muisca temple aligns directly with El Infiernito on the winter solstice at one of the important times of the Muisca calendar year (*socum*)--marking the start of new agricultural cycle (Restrepo 1895:162). The mountain fissures in this same area are major sources of water for the Rio Leyva which was integral to an irrigation system constructed by the Muisca.

The terrace platform is situated upon a high hill that appears to have been artificially leveled (below

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the peaks of the Cerro Santo) along the path of the solstice alignment midway between two mountain fissures (Figure 8). From this mountain, water flows into various stream channels leading into the Quebrada San Agustín, which flows around the hill and platform deep forming ravines on the west side that today requires a pedestrian suspension bridge. The hill platform is clearly terraced on the west side where huge megalithic stones aligned 238° show four extant tiers or stairs of dry-stone masonry. With many stones fallen or scavenged for recent construction, this architectural feature was probably originally longer and higher than what is seen today (Figure 9a). Encountered were diagnostic ceramics of the Late Muisca and Early Colonial periods, including a cached Fine Orange ring-based vessel (Figures 9b-c). There also appears to be more terracing on the east side along a possible access ramp or stairway leading down to water giving the entire structure a pyramidal shape, but only intensive survey and architectural excavation can determine this for sure.

The platform itself is supported by a 11-m stone retaining wall of cut stone masonry oriented 14° east of north with block cornerstones up to 100 cm tall (Figures 10a-b). The west wall exhibits stonework that could have supported a possible palisade and a raised stone surface on-platform near the northeast corner suggests a circular superstructure (*uta*) likely some form of Muisca perishable walled and roofed building (temple?). The west wall extends more than 20-m before integration into a zone of shaped megalithics some over 2 m long but fallen from their original upright positions. Many stones form a boulder alignment apparently as a division or western platform boundary (Figures 11a-b). In this area a Herrera phase potsherd was recovered and along the platform west wall were ceramics of all Muisca time periods (Figures 11a-c). These ceramic data indicate ceremonial activity spanning the entire indigenous occupation sequence and suggest that religious rituals were performed here until the founding of Villa de Leyva.

IV. Muisca Statues

Eight exquisite portrait statues from a private collection were examine in 2017 and are among the finest examples of pre-Hispanic stone carving known for the ancient Muisca (Figure 12a). Current evidence suggests that these statues were originally found at the same terrace-platform-temple or an associated context. Representing 12 individuals (6 males? and 6 females?), two adults (deities?) hug or hold from behind two seemingly adolescent children, while another adult holds two smaller children; all statues are three-dimensional portraits of seated-kneeling figures executed employing typical Muisca artistic conventions. In unsculpted form, interestingly, the stones resemble the shapes of the columns found at El Infiernito. Carved from local sandstone and limestone using stone tools. four statues are between 65 and 85 cm tall while the four smaller ones are about 25 to 35 cm. At least two of the larger statues exhibit a dark green patina or pigment, though it is difficult to rule out simple dirt or mold that has accumulated over the years. Three figures are damaged with impact scars resembling blows from a blunt instrument as well one statue which was repaired after a break at the waist and perhaps the top of the head. All statues show wear from being outdoors exposed to the elements for decades if not centuries suggesting great antiquity.

The statues are rendered in style and iconography typical for other Musica material culture: ceramics, goldwork, and textiles. All headgear are short conical caps, or *gorros*--some without decoration--others simply decorated with horizontal bands, pleaded-twisted rope, or simple triangles. One statue depicts long straight hair covering the ears hanging down at the back suggesting a female elite or deity figure. All others show shorter hair and stylized ears; one of the smaller male? statues is wearing earlobes and one female figure dones a stone necklace. However, one crown-like headdress, a sign of high rank, displays four vertical zones of complex symbols and motifs including spirals, embedded triangles bordered by horizontal bands set above a round element (jeweled mountains?), and a spiral flanking three dots topped by reptilian-like dorsal scales (Figure 12b).

Facial characteristics reveal elements of status and ethnicity. First, the wide, slit (closed?) eyes are stylistically Muisca as are the broad noses, though there are three figures with longer, thinner noses. Round owl-like eyes on one smaller statue suggest a transcendental animal-like appearance. Most notable are the decorations representing face painting (1-3 lines) but are noticeably absent on two bare chested females and two child faces (Figures 12c-d). One of the largest sculptures depicts cross-line painting on the cheeks as well as seven painted? notches on the bridge of the nose above a fanged mouth suggesting animal-like dentition. A child in arms shows half-moon symbols under both eyes perhaps lunar associations, while all other figures depict closed mouths some with thick lips, though one child mouth is open suggesting speech or sound. On all figures, the arms are in a natural position with hands resting at the waist or below the head of children figures; the fingertips are touching and six digits are represented on each hand.

Finding stone statues at a terrace-platform is not without precedence in Highland Muisca archaeology. Silva (1968) reported eight Muisca statues similar in style and size at two terrace platforms exhibiting a pyramidal form at La Salina de Mongua near Sogamosa, an isolated highland riverine setting some 80 km east of Villa de Leyva. Three of these statues, on exhibit at the Suamox Archaeological Museum, show similar decorative symbols and motifs as those described above (Figure 13). The Mongua site has been interpreted as a sacred religious temple for ceremonies and rituals related to a water cult and human fertility.

The Leyva statues are far superior in workmanship to the Mongua statues, which should not come at any great surprise because the Muisca of the Leiva Valley were famed stoneworkers actually responsible for building many of the early Colonial buildings at Villa de Leyva. Like the Mongua temple, the Leyva terrrace platform and statues must also relate to themes of water and fertility closely tied to worship of the sun as well as the origin myth of the Muisca. The alignment of the solar observatory at El Infiernito with a mountain water temple on the winter solstice surely emphasizes the great practical and cosmological significance of water for agricultural production. Human fertility is symbolized by female statues with large breasts (Bachué) while the portrayal of adults and children together clearly recalls the Legend of Iguaque.

V. Discussion and Conclusions

The observatory at Infiernito has been the subject of much public attention over the years mostly in the form of amateur archaeoastronomy conjecture and even wild pseudoscientific speculation. Non-scholarly interpretations have largely prevailed because so little is known of the ancient community and its hinterland which were integral to understanding the role of the stone monuments. Indeed, it was not until the 1980s that the archaeological establishment even recognized any community associated with the observatory. In addition, archaeological research of Highland Muisca chiefdoms in the Leiva Valley has not focused on the role of the natural environment despite the fact that dual wet and dry seasons vary greatly, drought is not uncommon, and farming without irrigation is often marginal at best. To redress this deficiency, environmental research into chiefdom ecodynamics has begun to contribute new archaeological evidence for intensive agriculture and water management. It is argued further that hydraulic systems in the Leiva Valley were closely tied to religious activity of a mountain water temple and astronomical-meteorological observatory at El Infiernito.

The preliminary data suggest that the El Infiernito observatory and water temple were important settlement features of the Muisca who observed a close cosmological relationship between the sun and water in both real and ritual terms. The precise diagonal alignment of stone columns connected to a water-related temple on the Winter Solstice undoubtedly marked a most significant time when the solar year ended and the agricultural cycle renewed. Born from a water mountain, this sacred water forming the Rio Leyva begins its journey towards the observatory, a symbol of fertility and solar power, that along the way was harnessed and controlled for agriculture via hydraulic means to ultimately sustain human fertility and the promise of continuing life.

Solar events and water mountains must have been times and places of cosmic ontogeny and ancestral origin. For the Muisca, the cosmology and environment of water were largely inseparable in that they saw no distinction or inconsistency between the physical and spiritual realms or actual or perceived aspects of their world. The uncertainties of drought, flood, famine, and hunger were all too real that required all manner of responses both tangible and intangible to survive the most significant challenges and unavoidable realities posed by their natural environment. In these regards, ecodynamic study explores the full-range of human adaptive abilities under conditions of environmental stress to determine how intermediate-level chiefdom societies responded to adverse climate-related conditions, a question largely unexplored in the archaeology of the Eastern Andean highlands. New understanding of the Muisca will add critical data about chiefdoms and diverse forms of subsistence agriculture no longer practiced in Highland Colombia. In this regard, multipartite ecodynamic approaches can represent an important new area of inquiry for archaeology and many of its allied disciplines.

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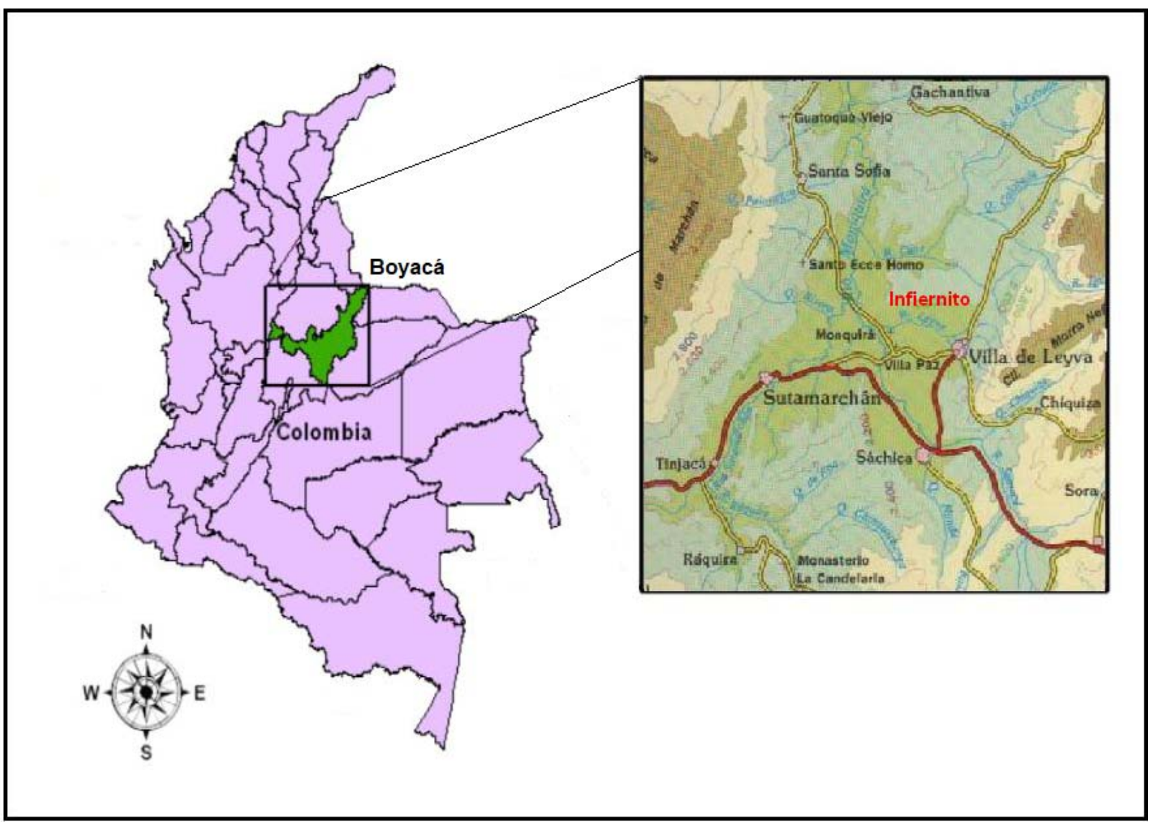

Figure 1: Map of Colombia and the Department of Boyacá showing the locations of Valley of Leiva, the site of El Infiernito, the town of Villa de Leyva, as well as other towns -sites throughout valley

Figure 2: Photo of El Infiernito Observatory looking north showing two rows of stone columns mostly reconstructed by Eliécer Silva Celis in 1981

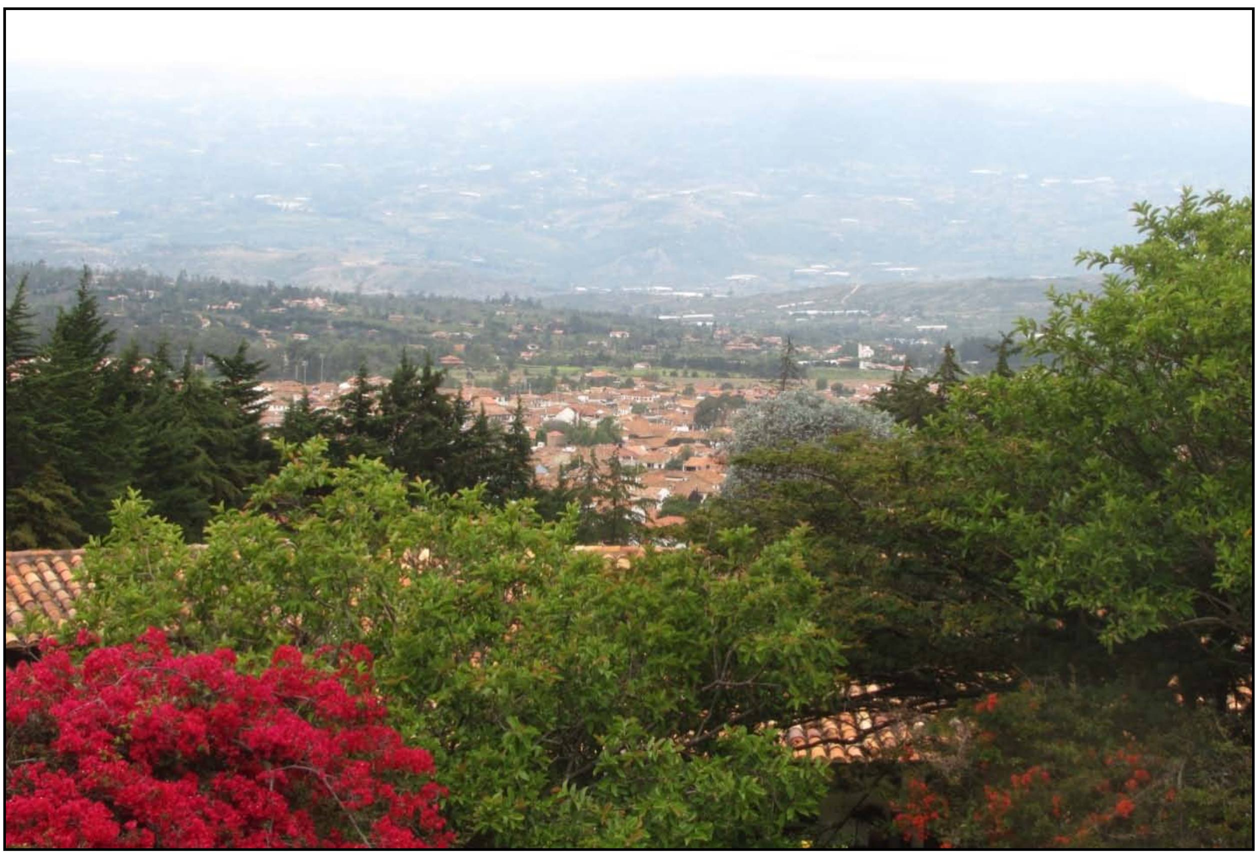

Figure 3a: Photo of the Valley of Leiva and Villa de Leyva looking northwest showing the location of El Infiernito and the Loma Carrera near the center-right of the photo

Figure 3b: Photo looking northeast of a potential hydraulic feature showing shaped megalithic slab boulders once standing upright and now partially displaced that served as walls for a reservoir above a check dam and downstream from a catchment zone and linear drain conduit. Sean-Michael Smyth stands to the right for scale

Figure 4: Photo looking east showing the replica Sun Temple of Suamox burned by Spanish Conquistadors in 1537 reconstructed at the Archaeological Museum in Sogamosa, Boyacá, Colombia

Figure 5: Photo of the principle Laguna de Iguaque looking east, the alleged mythological place of human creation mentioned in the Legend of Iguaque located at approximately 3,500 m elevation in the Iguaque National Park. This body of water does not directly align with Infiernito Observatory on the equinox as has been previously claimed

Figure 6a: Photo of the the north row (westernmost column) and south row (easternmost column) of El Infiernito Observatory looking along a diagonal azimuth for the Winter Solstice (~113°) aligning with the terrace platform-water temple, mountain water fissures for the Rio Leyva, and peaks of the Cerro Santo in the distance

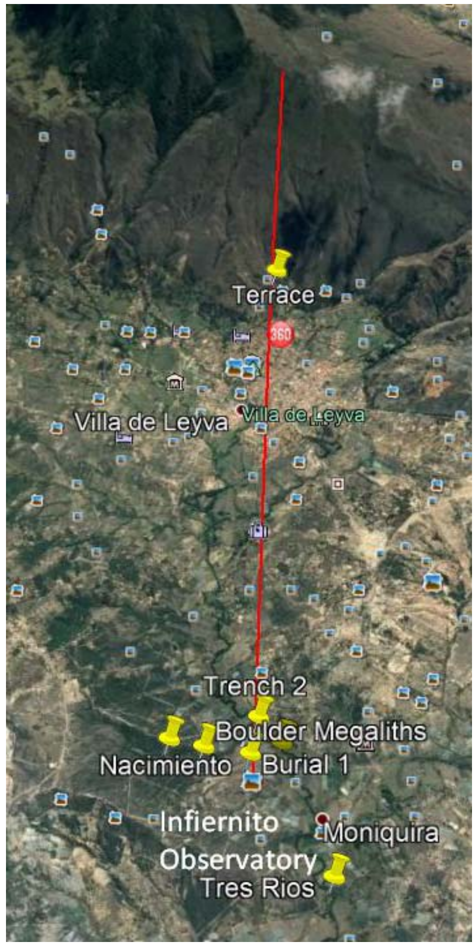

Figure 6b: Google satellite imaged of the Leiva Valley and Rio Leyva illustrating the actual azimuth (112° of the Winter Solstice (red line) passing from the El Infiernito Observatory to the terrace platform-water temple, mountain water fissures for the Rio Leyva, and peaks of the Cerro Santo some 7.118 km to the east-southeast where the winter sun appears on December 22nd

Figure 7a: Photo of a colonial street of Villa de Leyva looking east-southeast towards the peaks of the Cerro Santo and the mountain water fissures and stream channels adjacent to the terrace platform where the sun of the Winter Solstice rises

Figure 7b: Close-up photo looking east showing the path of water from the mountain fissures and stream channels overlooking the terrace-platform that lead to the Quebrada San Agustín and Rio Leyva

Figure 8: Forested areas looking northeast surrounding the leveled hill for the terrace platform-water temple (center), adjacent stream channels, and the Quebrada San Agustín

Figure 9a: Photo of the megalithic terrace tiers (or stairs) along the west side of the hill leading to the terrace platform-water temple. Dry stone masonry with abundant chinking stones and Prehispanic and Early Colonial ceramics were associated with this stone structure. Stones for the upper level courses have fallen, were removed, or reused recently

Figures 9b and 9c: Photos of a low ring-base plate of Fine Orange found partially buried within and eroding out of the upper course area of the Megalithic Tiers (b), and the partial reconstruction of the same vessel (c). This vessel is believed to date to the Late Muisca or Early Colonial Periods (ca.1500 to 1572 A.D.)

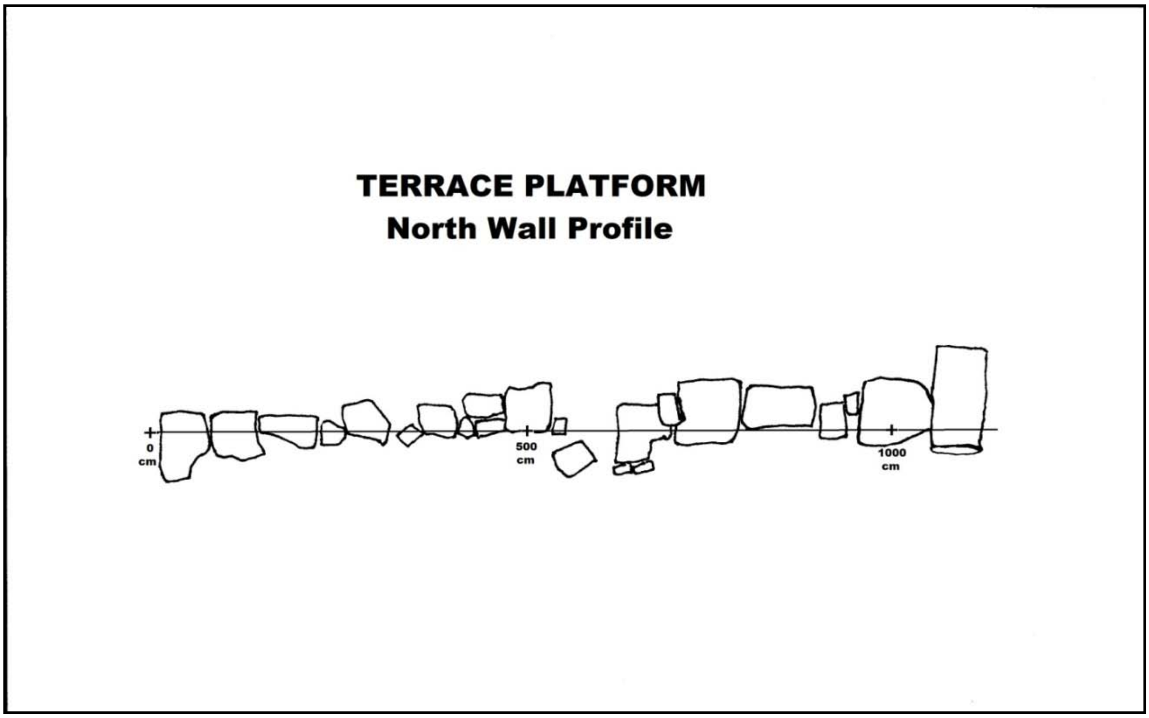

Figure 10a: Profile map of the Terrace Platform north wall on the hilltop

Figure10b: Photo looking east showing the aligned and faced monolithic stones for the Terrace Platform north wall

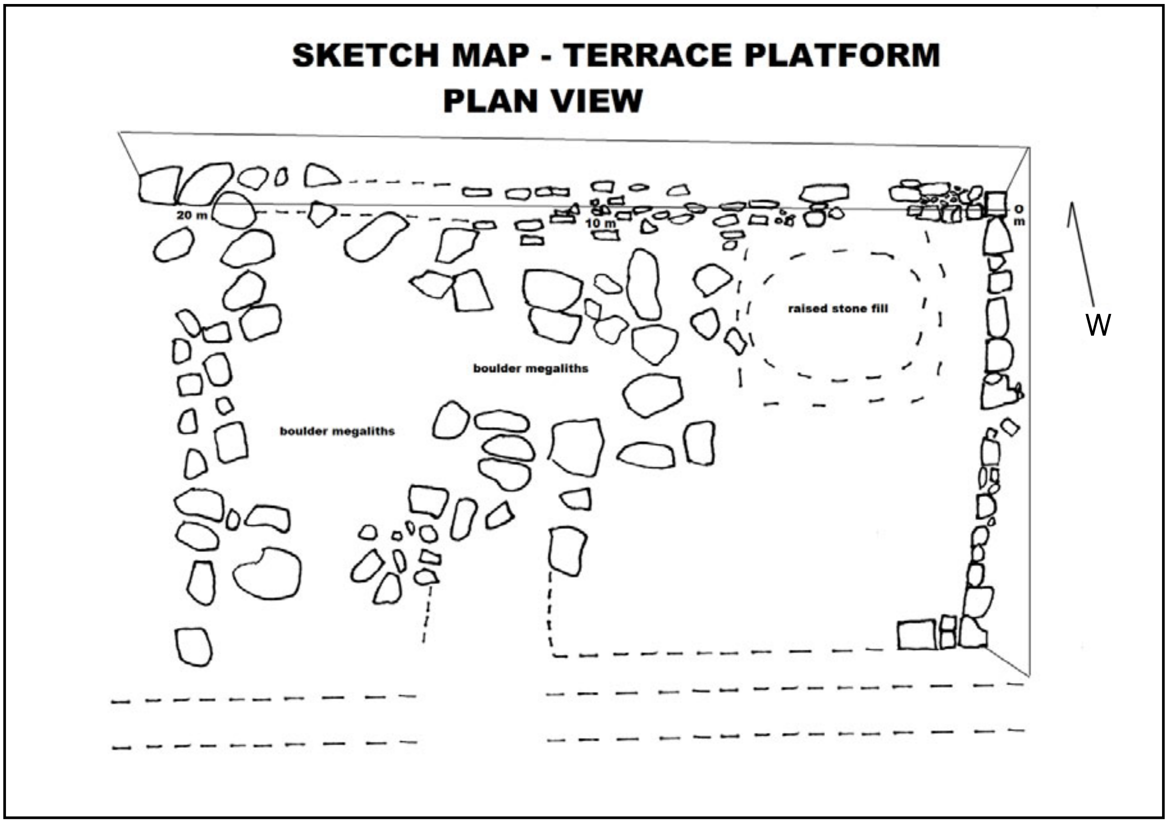

Figure 11a: Plan view sketch map of the Terrace Platform showing a west retaining wall, a northwest area of stone fill or pavement possibly for a circular temple *(uta)* and numerous shaped-carved monolithics many displaced and showing an alignment for a division or platform border area. The platform is terraced on the east side leading down to water. Herrera Phase, Early Muisca, Late Muisca, and Early Colonial Period ceramics were found on- and off-platform

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Figures 11b-c: Cut and shaped boulder megaliths on the platform surface many of which are now displaced and appeared to have been originally upright and spatially arranged. Some of these megaliths are still aligned forming a western border or division for the terrace platform

Figure 12a: Photo of eight carved limestone and sandstone portrait statues exhibiting typical Muisca decorative symbols and motifs from a private collection. These statues allegedly were found on or near the Terrace Platform. Many appear to be deity or elite figures associated with fertility (Bachué) and the origin myth of Iguaque

Figure 12b: Close-up of one of the largest statues seemingly an elite figure holding an adolescent child recalling the-Legend of Iguaque

Figure 12c: Maternal figure symbolizing fertility and perhaps depicting Bachué, an earth goddess and mother of humanity among the Muisca

Figure 12d: Smaller statue of an adult holding two smaller children perhaps also related to the Iguaque origin myth

Figure 13: Photo at the Archaeological Museum of Suamox in Sogamosa showing four Muisca stone portrait statues flanking a blackstone decorated disc adjacent to a frog fertility symbol within a reflecting pool. These statues were found at terrace platforms with Salinas de Mongua similar to those near Villa de Leyva

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Extent & Impact of Land Degradation and Rehabilitation Strategies: Ethiopian Highlands

By Merkineh Mesene
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Abstract- Throughout the world today, depletion of natural resources is among the major problems facing human beings. Land degradation, especially in the highlands, has been identified as the most serious environmental problem in Ethiopia. The Hararghae highlands in Eastern Ethiopia, Tigrai, Wollo, and Semen Shoa highlands in the north and the Gamo- Gofa highlands and the Bilate River basin, which starts in eastern slopes of Gurage highlands and stretches through eastern Hadiya and Kembatta highlands are some of the seriously eroded/degraded land surfaces in Ethiopia. The dominant man induced causes of land degradation in Ethiopia are poor farming practices, population pressure, overgrazing, over cultivation, soil erosion, deforestation, salinity and alkalinity problems, and the use of livestock manure and crop residue for fuel as energy resource of the rural households. The recorded annual soil erosion (surface soil movement) in Ethiopia ranges from low of 16 tons/ha/yr to high of 300 tons/ha/yr depending mainly on the slope, land cover, and rainfall intensities. The total estimated annual soil loss (surface soil movement) from the cultivated, range and pasture lands (780,000 km^2) in Ethiopia is estimated to range from low of 1.3 to an average of 7.8 billion metric tons per year. Study put the degraded area on the highlands at 27 million ha of which, 14 million hectares is very seriously eroded with 2 million ha of this having reached a point of no return, and the soil depth is so reduced that the land is no longer able to support any vegetative cover.

Keywords: land degradation, rehabilitation strategies, ethiopian highlands.

GJHSS-B Classification: FOR Code: 040699p

EXTENTIMPACTOFLANDDEGRADATIONANDREHABILITATIONSTRATEGIESETHIOPIANHIGHLANDS

Strictly as per the compliance and regulations of:

Extent & Impact of Land Degradation and Rehabilitation Strategies: Ethiopian Highlands

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Abstract- Throughout the world today, depletion of natural resources is among the major problems facing human beings. Land degradation, especially in the highlands, has been identified as the most serious environmental problem in Ethiopia. The Hararghae highlands in Eastern Ethiopia, Tigrai, Wollo, and Semen Shoa highlands in the north and the Gamo-Gofa highlands and the Bilate River basin, which starts in eastern slopes of Gurage highlands and stretches through eastern Hadiya and Kembatta highlands are some of the seriously eroded/degraded land surfaces in Ethiopia. The dominant man induced causes of land degradation in Ethiopia are poor farming practices, population pressure, overgrazing, over cultivation, soil erosion, deforestation, salinity and alkalinity problems, and the use of livestock manure and crop residue for fuel as energy resource of the rural households. The recorded annual soil erosion (surface soil movement) in Ethiopia ranges from low of 16 tons/ha/yr to high of 300 tons/ha/yr depending mainly on the slope, land cover, and rainfall intensities. The total estimated annual soil loss (surface soil movement) from the cultivated, range and pasture lands (780,000 km^2) in Ethiopia is estimated to range from low of 1.3 to an average of 7.8 billion metric tons per year. Study put the degraded area on the highlands at 27 million ha of which, 14 million hectares is very seriously eroded with 2 million ha of this having reached a point of no return, and the soil depth is so reduced that the land is no longer able to support any vegetative cover. Land degradation costs/indicators are reduced yield, change in land-use, and change in crops, abandonment of fields, and altered livestock mixes and patterns of grazing, flooding, changes in stream flow, silting of rivers & dams, unreliability of irrigation water flow and decline in quality of drinking water and ground water, loss of environmental services, migration and associated loss of human capital and break up of communities, social costs of poverty, and reduced ability to invest in anti-degradation activities, loss of soil from farm plots and the loss of nutrients resulting in decreased productivity or the need for increased inputs to maintain productivity. Therefore, to minimize or avoid the current and potential undesirable consequences, proper attention must be given to the degraded areas in the country. Rehabilitation measures of degraded lands improve the overall ecological conditions of degraded areas so that they can provide better socio-economic benefits, Biodiversity and environmental services to the local communities.

Keywords: land degradation, rehabilitation strategies, ethiopian highlands.

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I. Introduction

Environmental problems in the developing world are closely linked with the use of the environmental resources particularly land resources [61]. Land degradation is worldwide problem with its acuteness in developing countries. "The fight against drought, land degradation and desertification is now an international priority, and our Strategy is the battle plan, signaling an ambitious yet pragmatic new departure in the life of our Convention" [70] was the introductory speech by General secretary of the UNCCD on high level policy dialogue. Land degradation is one of the major socio-economic and environmental problems, affecting one billion people in 110 countries worldwide and is prevalent across about 40 percent of the earth's surface [72] and [23]. Land degradation may occur at any time in any geographical region of the planet. It is limited neither by space and time nor by particular natural circumstance. However, specific types of land degradation problems and the level of severity exhibit considerable differences across various parts of the world [74] and [76]. It is an increasing problem in many parts of the world. Success in fighting land degradation requires an improved understanding of its causes, impact, degree and relationship with climate, soil, water, land cover and socio-economic factors [46]. Natural resource degradation in general and land degradation in particular has a great effect on the economies of developing countries. It is one of the most critical environmental issues facing many countries today [11]. In Africa, it is estimated that about 320 million ha, or about one quarter of its dry lands, are affected by different types of soil erosion [4]. The economy of many developing countries, including Ethiopia, is heavily dependent on agriculture, and the livelihoods of the vast majority of their populations depend directly or indirectly on this sector. This dependence on agriculture increases the vulnerability of the economy of these countries to problems related to land degradation [76].

Land is being the critical agricultural resource and the basis for survival of most people in Ethiopia. The largest proportion of the employment for labour is contributed from the agriculture sector. In spite of this, land is seriously threatened by land degradation throughout the country, threatening both the economic and survival of the people. It is a severe problem that leads to low agricultural productivity, which aggravates food security problems [36] and one of the major environmental threats that have well been acknowledged as a serious problem in Ethiopia. Land degradation in Ethiopia is a result of complex and interacting processes including adverse changes in soils, water, vegetation, biodiversity, and local climatic resources [58].

The Ethiopian highland studies revealed that the Ethiopian highlands, which cover 44% of the country's total land area are seriously threatened by soil and biological degradation. Land degradation, especially in the highlands, has been identified as the most serious environmental problem in Ethiopia [10]. Some 27 million ha representing approximately 50% of the highlands are already significantly degraded. Of this area 14 million ha are badly eroded and if the present trend of soil degradation continues, per capita income in the highlands will fall by 30% in 20 years' time. Around 54% of the remaining highlands are highly susceptible to erosion ([29]; [30]).

According to ([29]; [2]) the Hararghae highlands in Eastern Ethiopia, Tigrai, Wollo, and Semen Shoa highlands in the north and the Gamo-Gofa highlands and the Bilate River basin, which starts in eastern slopes of Gurage highlands and stretches through eastern Hadiya and Kembatta highlands are some of the seriously eroded/degraded land surfaces in Ethiopia. As in [3] in Ethiopia land degradation, declining agricultural productivity, and poverty are severe and interrelated problems that appear to feed off each other. In light of the increasing population and the low levels of urbanization, all projections indicate that land degradation in Ethiopia is bound to proceed at aggravated rates unless significant progress is made in conservation, rehabilitation, and restoration.

The general aim of this paper is to review the magnitude, extent, causes, consequences and potential impacts of land resource degradation and rehabilitation strategies in Ethiopian Highlands.

II. Results and Discussion

a) *The Concept of Land and its Resource Deterioration*

Land is internationally defined as "a delineable area of the earth's terrestrial surface, encompassing all attributes of the biosphere immediately above or below this surface, including those of the near surface climate, the soils and the terrain forms; the plant and animal population, the human settlement pattern and physical results of past and present human activity" [77]. It is the main resource on which our society depends for production of food, energy and other requirements [58].

Land degradation and soil degradation are often used interchangeably; however land degradation has a broader concept and refers to the degradation of soils, water, climate, and fauna and flora [6]. It refers to changes in the qualities of soil, water and other characteristics that reduce the ability of land to produce goods and services that are valued by humans [36]. The term land degradation refers "the aggregate reduction of the productive capacity of the land, including its major uses like rain fed, arable, irrigated range land, forest and its farming systems such as smallholder subsistence and its value as an economic resource" ([63]; [4]).

It is also broadly defined as any form of deterioration of the natural potential of land that affects ecosystem integrity either in terms of reducing its sustainable ecological productivity or in terms of its native biological richness and maintenance of resilience. It is a worldwide phenomenon substantially affecting productivity in over 80 countries on all continents [35]. It is in Africa a serious problem with a considerable impact on the economies of many countries in the continent. About 25 percent of the world's degraded land is located in Africa ([58]; [56]). Land degradation is a composite term; it has no single readily-identifiable feature, but instead describes how one or more of the land resources such as soil, water, vegetation, rocks, air, climate, relief has changed for the worse [63].

The cause of land degradation may be single or a complex mix of causes. Some are bio-geophysical; some socio-economic (human) activities, while some are institutional factors like inadequate land policy frameworks and it is quite possible that causes may be indirect, perhaps cumulative and difficult to identify [28]. Population pressure is given emphasis on the speech as the significant factor that is aggravating land degradation.

Ecological restoration is an intentional activity that initiates or accelerates the recovery and sustainability. Frequently the ecosystem that requires restoration has been degraded, damaged, transformed or destroyed as those direct or indirect human activities [7]. Rehabilitation is a broader term that refers to any attempt at repairing or restoring a damaged ecosystem, without necessarily attempting a complete restoration to any specific prior conditions or status. In essence both restoration and rehabilitation are similar, but unlike restoration, rehabilitation contains little or no implication of recreating the original ecosystem. The word 'rehabilitation' is used to indicate any act of improvement from a degraded state ([62]; [40]). Restoration is defined as the return of an ecosystem both the structure and the function to a close approximation of its condition prior to disturbance ([21] and [52]).

In Ethiopia, rehabilitation starts with area closure that involves the protection and resting of severely degraded land to regenerate its productive capacity [78]. Continuous deterioration of the natural resource base has become a serious threat to both ecosystem functions and economic production of Ethiopia. To combat these problems national level environmental conservation and rehabilitation efforts were started in the 1970s with particular focus on the forest deteriorating highland areas [13] and are focusing mainly on installing biophysical measures or structures and pay less attention to the socio-economic and institutional side of the problem. This had led to poor performance of many of the environmental reclamation programmes in Ethiopia [5].

b) Land Degradation in Ethiopian Highlands

The highland areas in Ethiopia are defined and delineated to represent the land areas above 1500 m a.s.l. and the lowlands are defined as areas below 1500 m a.s.l. in altitude. More than 90% of Ethiopia's population live in the highlands including about 93% of the cultivated land, around 75% of the country's livestock and accounts for over 90% of the country's economic activity. Land degradation is seriously threatening the economic and social development of the country as a whole. Due to degradation, increasing number of Ethiopians have become vulnerable to the effects of drought. The severity of the devastating droughts and the resulting famines in 1972/73 and 1984/85 can be attributed to an accelerating process of degradation combined with widespread general poverty of the population [29].

i. *Severity and Consequence of land degradation in the Country*

There is no region of the globe where water erosion is not a threat to the long-term sustainability of mankind. Accelerated soil erosion is the one influenced by man through overgrazing, cultivation, road construction and monocultures on steep land without conservation measures (Alemayehu, 2009). According to [33] Ethiopia faces the most pressing and difficult problems in feeding its population. FAO described that between1996-98 more than 35 percent of the population of the country was undernourished and high-energy deficit. Land degradation due to soil erosion and nutrient depletion, cause a serious problem on the livelihood of the rural producers.

Ethiopia's fast-growing population is also significantly hurrying land degradation. The population has tripled in the last 50 years and has abused the land by deforestation for more cropland and grazing area and by overgrazing. Recurrent droughts have further aggravated the situation, leading to repeated cycles of famine in recent years. Efforts are being made to avert the degradation, but with very little progress [59].

Land degradation in the form of soil erosion and declining fertility in the country is serious challenge to agricultural productivity and economic growth [52]. Soil erosion by water is by far the greatest land degradation problem. Water erosion not only removes nutrients but also may reduce thickness and the volume of water storage and root expansion zone. Under extreme gully erosion, farm activities are extremely affected. The magnitude and rate of soil erosion continued to increase despite the considerable efforts made during the past three decades. The soil conservation research project estimated an average soil loss of the 42 t/ha/year on cultivated lands and in highly erodible and intensively cereal cultivated fields it ranges 300-400 t/ha/ year [1].

Table 1: Soil loss from three measure land use sytems [44]

Type of land use	Topographic features	Annual soil loss
Cultivated Land	Steep slope	>100t/ha
Grazing Land	Flat-undulating	<10t/ha
Forest Land	Undulating	10t/ha

Table 2: Comparison between predicted and observed (Ethiopia) [55]

Research Site	Slope Gradient [%]	Calculated Soil Loss (mean)	Measured Soil Loss (Mean)	Remark
Andit Tid	39		212t/ha	
	40	686t/ha		
Anjeni	12		213t/ha	
	10	20t/ha		
Maybar	16		22t/ha	
	16	24t/ha	-	

Table 3: Soil loss under different crop variety [55]

Source of information	No of plots	Crop Type	Soil loss	Remark
SCRP 2000b, 41:	7	Wheat	185.1t/ha*a	
	12	Lentil	180t/ha*a	
	10	Barley	141.1t/ha*a	
SCRP 2000c 40:	4	Wheat	192.6t/ha*a	
	6	Teff	178.3t/ha*a	
	5	Barley	111.9t/ha*a	
	3	Horse Beans	115.5t/ha*a	

The implications of land degradation are extremely important, as the livelihoods of many Ethiopians are entwined with land resources. Degradation reduces the production potential of land, and thus makes it difficult to produce enough food to feed the growing population. It also increases farmers' vulnerability to food shortages and becomes a threat to the mere survival of the people. The looming food insecurity in the country is mainly linked to the prevailing degradation problem [4]. Land degradation impacts were assessed in social and economic terms only for soil erosion. Four types of costs were specified such as lost cropland, lower crop yield, lost grazing land, and lower grass yield. These costs were compared to costs incurred in the absence of soil erosion [3]. Associated with the soil movement is the loss of organic matter, nitrogen, phosphorus, potassium and other essential plant nutrients [41].

ii. *The cost of land degradation in Ethiopia*

Land degradation represents a loss of natural capital, the value to society of land, water, plant, and animal resources. Indicators are reduced yield, change in land-use, and change in crops, abandonment of fields, and altered livestock mixes and patterns of grazing [12]. The quality of environmental services indicated by such processes as changes in stream flow, silting of dams, unreliability of irrigation water flow and decline in quality of drinking water. These losses also result in costs related to changes in rural society due to processes such as migration and associated loss of human capital and break up of communities, social costs of poverty, and reduced ability to invest in anti-degradation activities. Most current evaluations of the costs of land degradation have focused on the loss of soil from farm plots and the loss of nutrients resulting in decreased productivity or the need for increased inputs to maintain productivity [4].

Table 4: Annual loss of OM, N and P associated with the loss of top soil under various land use systems [42]

Land use type	Land area million ha		Nutrient documented range of annual loss, kg/ha					
		OM	15	50	100	200	500	1000
		N	5	10	15	30	50	65
		P	15	30	50	75	100	150
			Amount of nutrient loss, million kgs					
1. Cultivated land	18	OM	270	900	1800	3600	9000	18000
		N	90	1800	270	360	900	1170
		P	270	360	900	1350	1800	2700
2. Pasture & rangelands	60	OM	900	3000	6000	12000	30000	60000
		N	300	600	900	1800	3000	3900
		P	900	1800	3000	4500	6000	9000
Total	78	OM	1170	3900	7800	15600	39000	78000
		N	90	780	1170	2160	3900	5070
		P	1170	2160	3900	5850	7800	11700

Table 5: Annual soil movement (loss) documented in Ethiopia under various land use systems and topographic features [42]

Land use type	Land area million ha	Documented range of annual soil loss, ton/ha/year 16	50	100	200	300
		Annual soil movement, million tons				
1. Cultivated land	18	288	900	1800	3600	5400
2. Pasture & rangelands	60	960	3000	6000	12000	18000
Total	78	1248	3900	7800	15600	23400

Land degradation has direct and indirect costs.

Direct costs include:

- The costs of nutrients lost through topsoil erosion and the cost of replacing these nutrients.
- The production that is lost because of nutrient and soil losses.
- The costs of forest removal.
- The loss of livestock carrying capacity.
- The decline in cropped area.

Indirect costs mainly include:

- ✓ The loss of environmental services.
- ✓ The silting of rivers and dams.
- ✓ Increasing irregularity of streams and rivers.
- ✓ Reduced groundwater reserves.
- ✓ Flooding.
- ✓ Other costs, related to social and community losses from malnutrition, poverty and migration

A number of conceptual issues interrupted on estimates of the cost of land degradation, the most important of which are definitional guess. Such as differentiate between land degradation and soil degradation. These terms are often used interchangeably but are not necessarily synonymous. Land degradation is a broad, composite, and value-laden term that is complex to define but generally refers to the loss or decline of biological and/or economic production. [71] defines land degradation as a reduction of resource potential by one or a combination of processes including water erosion, wind erosion, a long-term reduction in the amount or diversity of natural vegetation. Soil degradation is a narrower term and a component of land degradation. It refers to a process that lowers the soil's current and/or potential capacity to produce goods or services. Six specific processes are recognized as the main contributors to soil degradation are soil erosion, wind erosion, water logging, excess salts, chemical degradation, biological degradation, and physical degradation [19].

Most studies estimating the costs of land degradation restrict themselves to on-site impacts; the analysis of off-site effects, although frequently recommended, is rare. It is usually conducted only in qualitative terms because it is difficult to measure such impacts. The implication is that tendered values often underestimate actual costs [3].

[30] Tried to assess the magnitude of the degradation problem in social and economic terms. Referring to the conclusion in 1981 of a USA National Soil Erosion/Soil Productivity Research Planning Committee that "erosion reduces productivity first and foremost through loss of plant-available soil water capacity", and the need to consider the relation between erosion induced yield reductions and remaining soil depth. It is difficulty of estimating these in the Ethiopian highlands. Because of slopes in much of the cropland in the Ethiopian highlands are much steeper.

Impact on Production and Environment Rehabilitation

As from [42]; the major impacts of land degradation on production and env't rehabilitation include:

- Soil loss caused by erosion reduces soil depth, consequently decreasing the amount of soil moisture and leading to the loss of plant nutrients. This contributes to the loss of grain production in the order of 80,000–180,000 tons per year ([57]; [29]). In addition, if the present soil erosion rates stay at their current levels, it is projected that land covered by soil less than 10 cm deep will increase from 20,000 km2 in 1985 to 100,000 km^2 by 2010, contributing to large losses to crop production potential.
- The estimated soil movement ranges from 1,248 to an average value of 7,800 million tons per year causes a loss of organic matter of the order of 1.17–7.8 million tons, nitrogen from 0.39 to 1.17 million tons and phosphorus 1.17–3.9 million tons per year. The yearly loss of nitrogen and phosphorus from 780,000 km2 of cultivated, pasture and rangelands in Ethiopia is estimated to be equivalent to 327–1064 million US dollars per year [42].

- The recurring droughts and low, erratic rainfall are responsible for the loss of thousands of human lives, millions of livestock and annual crop loss of up to 20% during severe drought years in-terms of grain produced (1,8 million tons per year).
- The present burning of animal dung and crop residues for fuel is estimated to represent a loss in crop production of 700,000 tons of grain [57].
- The estimated annual loss of forests of between 150,000 and 200,000 ha is equivalent to about 6% of the remaining natural high forest. At this rate the natural forests will be gone in 15–20 years [24].

Table 6: Soil erosion loss on 6 SCRP sites in various parts of Ethiopia [18]

Site	Soil loss (tons/ha/year)
South Wollo	36.5–53.8
Sidamo	41.2–49.5
Harar	25.5–27.8
North Showa	152.4–214.8
Gojam	40.2–199.2
Illubabur	18.0–135.3

c) *Causes and Consequences of land degradation*

i. *Causes of land degradation*

Land degradation is one of the major causes of low and in many places declining agricultural productivity and continuing food insecurity and rural poverty in Ethiopia. Part of the reason for lack of solution to the problem is the need for multiplex approaches; "one size fits all" approaches won't solve the problem in the heterogeneous environment of the Ethiopian highlands. Therefore, there is a need to identify what works where and provide farmers an array of potentially effective options, as well as addressing constraints that inhibit adoption of potentially effective measures through appropriate policies and investment programs. The causes of land degradation can be divided in to natural hazards, direct causes, and underlying causes. Natural hazards are the conditions of the physical environment, which leads to the existence of a higher degradation hazard. Land degradation is the result of complex interactions between physical, chemical, biological, socio-economical, and political issue of local, national or global nature [31] and [65].

Causes of land degradation are not only biophysical, but also socioeconomic like land tenure, marketing, institutional support, income and human health; and political incentives, political stability. Land degradation damages soil structure and leads to the loss of soil nutrients through processes such as water or wind erosion; water logging and salinization; and soil compaction. The main causes of land degradation are inappropriate land use, mainly unsustainable agricultural practices, overgrazing, and deforestation [56].

According to [71], the effects of deforestation, forest degradation and forest fires represent a permanent loss of the potential capacity of forest resources to generate economic benefits. Deforestation is a major issue in Ethiopia, since it is one of the main causes of the prevailing land degradation and loss of biodiversity. Tree cutting is a common occurrence which has been taking place for centuries [56]. A long time back in history some parts of northern Ethiopia, which are today suffering from conditions caused by land degradation, were covered with forests. In present day Ethiopia, however, forests are being destroyed at an alarming rate and the area covered by forests at present is only less than 2.4 percent compared to the estimated 40 percent before one hundred years initial coverage [45].

a. *Direct causes of land degradation*

There is a general agreement on the direct causes of land degradation. These include production on steep slopes and fragile soils with inadequate investments in soil conservation or vegetative cover, erratic rainfall patterns, decline uses of fallow, limited recycle of dung and crop residues to the soil, limited application of external source of plant nutrients, deforestation and overgrazing. Many factors underlie these proximate or direct causes including population pressure, poverty, high costs of inputs and limited access to agricultural inputs and credit, low profitability of agricultural production and many conservation practices, high risks facing farmers, fragmented land holdings and insecure land tenure, short time horizons of farmers and farmers' lack of information about appropriate alternative technologies [4].

There are four major causes of land degradation such as deforestation, overgrazing, agricultural activities, and over exploitation. The well known proximate causes of land degradation include deforestation, overgrazing, limited soil and water conservation measures, limited application of nutrients/organic matter, burning of dung and crop residues and declining use of fallow [32] & [76].

Agricultural mismanagement of soil and water resources include non-adoption of soil and water conservation practices, improper crop rotation, use of marginal land, insufficient and/or excessive use of fertilizers, mismanagement of irrigation schemes and over pumping of ground water [33]. Lack of early awareness about soil erosion and soil fertility decline by farmers is another possible cause of land degradation [69]. These all are direct causes of land degradation primarily caused by human intervention exposing natural resources to depletion and loss. Human interventions expose the soil to erosion and induce depletion of natural capital asset of society [76].

b. *Indirect causes of land degradation*

Population increase, land shortage, insecure land tenure, poverty and economic pressure are indirect causes of land degradation [32]. Population growth has long been considered a prime cause of environmental degradation [9]. It forces farmers to cultivate marginal land. With current trend of population growth there is a poor prospect for ecological sustainability and economic viability of the current agricultural practice unless an effort is made to integrated development in family planning, environmental rehabilitation, and agriculture supported with enabling policy [32].

A study made in north western Ethiopian highlands by [37] concluded the absence of sound land use tenure policies (frequent changes in the tenure systems and frequent distribution of land), population pressure, weak economic development strategies, unstable institutional frame works, and weak link between research and extension have all been found to be root causes of land degradation and are major policy constraints that discourage the farmer from making any sort of investments in the land to use it in a suitable way. When families believe that the land tenure system is unfavorable to them, they are reluctant to invest in good agricultural practices, such as soil and water conservation and management. In similar way, in Ethiopia with the lack of land ownership, farmers have the tendency to make the land less attractive to others [33]. The current land policy of Ethiopia, i.e., the right to use and transfer to their children is expected to affect long term investments including construction of conservation bunds, planting trees, short term fallowing and alike [69]. In addition to insecure tenure, communal grazing land and wooded areas for the extraction of firewood give rise to land degradation [36].

ii. *Consequences of land degradation*

According to UNCCD, the consequences of land degradation include undermining of food production, famine, increased social costs, decline in the quantity and quality of fresh water supplies, increased poverty and political instability, reduction in the land's resilience to natural climate variability and decreased soil productivity [56]. Land degradation effects on agricultural productivity are manifested through their impacts on both, the average and variance of yield, as well as the total factor productivity of agricultural production [33]. It affects agricultural productivity, leads to clearance of forests and native grasslands as existing land loses productivity, places demands on other natural resources to repair the land. These impacts are translated into economic costs in the form of loss of income (or consumption), increased income risk and increase costs of production.

Soil degradation has resulted in decreased food production, droughts, ecological imbalance and consequent degradation of the quality of life. The SCRP has estimated that about 1.5 billion tones of soil are eroded every year in Ethiopia [32]. Similarly, the Ethiopian high lands reclamation study estimated that between 1985 and 2010 the rates of land degradation will cost 15.3 billion Ethiopian Birr, most of which (78 percent) is due to crop failure or low yields and 22 % is due to decreased livestock population [68]. As commonly known degraded soils rarely respond to mineral fertilizers, have very poor water-holding capacity, and totally have low productive capacity that manifests itself through decreased food production [36]. In addition to its natural capital asset depleting effect, soil erosion also induces immediate on site effects, those that happen at the site where erosion occurs, and off-site effects which have positive or negative effects as the soil leaves the boundary or the field due to erosion and enters another field or watershed [76].

d) *Rehabilitation strategies of degraded lands in Ethiopia*

i. *Soil and Water Conservation Practices*

Ethiopia has been seriously affected by soil erosion for centuries. To achieve sustainable development, ecologically friendly and locally acceptable technologies need to be developed, transferred and adopted. Natural resources can potentially be used in a sustainable way through appropriate technology. Following the sustainability pattern, "appropriate", would require that a technology should be ecologically protective, socially acceptable, economically productive, viable and reduces risk [43]. Management of watersheds can be made possible by using a variety of technologies such as vegetation conservation like grass contours, alternative tillage techniques and physical structures including terraces, micro basins, stone and soil bunds, *fanya juu* (throw up hill), gabion box, etc [34].

To combat the land degradation problem, the Ethiopian government launched a massive soil conservation programme in the middle of 1970's. The following physical and biological conservation measures were carried out between 1976 and 1992 such as 78,000 ha of soil and stone bunds; 253,000 ha of hill side terraces and afforestation ;15,400 km of check dams in gullied lands ; 410,000 ha of closed areas of natural regeneration (area enclosure);465,000 ha of land planted with different tree species; 580,000 ha of bench terraces; National conservation strategy has been completed and ratified; Action plan to combat desertification is under way; National population policy is adapted; Disaster prevention and preparedness programme has been approved and implemented; Ethiopian Forestry Action plan has been prepared; Environment Protection Agency has been established; and Agricultural development and environment rehabilitation are given first priority in the Government of Ethiopia's Economic Development Policy ([41]; [42]; [18]; [24]).

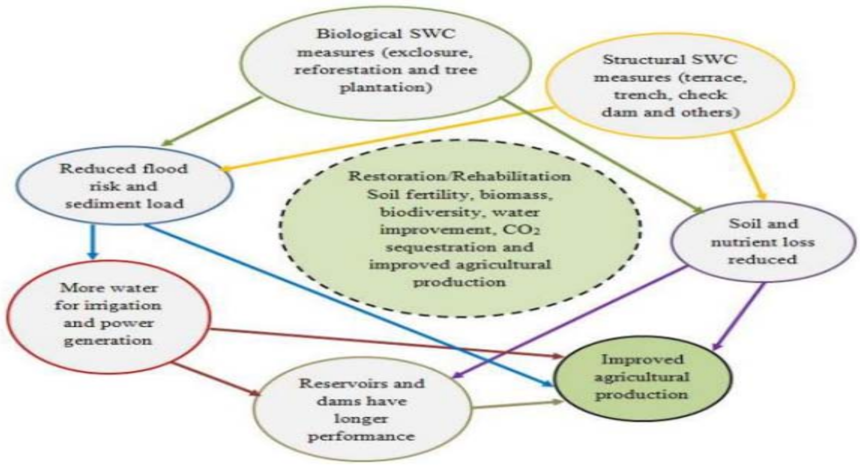

Figure 1: Conceptual framework demonstrating implication of SWC measures in degraded land rehabilitation [22]

Degraded soils are a major constraint to agricultural production and food security in the southern Ethiopian Highlands. Despite experiencing problems with degraded soils and food insecurity, and acknowledging the potential benefits of certain technologies, many farmers in Areka may decide not to integrate these techniques into their production system. Soil conservation measures often reduce the amount of available farmland and incur additional costs. More farmers may be willing to adopt soil and water conservation measures if they provide immediate additional benefits, such as the potential to generate extra income [8] & concluded in the table below.

Table 6: Perceptions of integrated soil fertility management measures according to different socio-economic groups[8]

Practice	*Wealth group I*		*Wealth groups III &IV*	
	Advantages	*Disadvantages*	*Advantages*	*Disadvantages*
Legume cover crops	• Enhance soil fertility • Provide fodder • Conserve soil moisture	• Compete for land • No immediate benefit	• Protect soil from sunlight and runoff	• Occupy space for long time • No food value
Crop rotation	• Enhance soil fertility • Less fertiliser requirements • Pest control	• None	• Enhances soil fertility • Improves yield	• None
Incorporating crop residues	• Improves soil fertility • Increases yield	• Shortage of animal feed	• Improves soil fertility	• Shortage of fuel and fodder
Soil bunds	• Reduce runoff • Possible to plant grasses & perennials	• Require a lot of labour • Ploughing with oxen difficult	• Erosion control	• Require a lot of labour • Take up land
Increased vegetative cover	• Controls runoff • Provides fodder and fuelwood • Provides litter for green manure	• Makes it difficult to control perennial weeds	• Increases availability of fodder • Controls runoff	• Competes for land and moisture
Mulch	• Conserves moisture • Improves soil fertility	• Reduces supply of fuelwood and fodder	• Conserves moisture • Improves fertility	• Attracts termites
Minimum tillage	• Reduces labour and costs • Reduces erosion	• Hard to control weeds • Crops establish poorly • Hard to cultivate	• Reduces cost of hiring oxen	• More weeds • Crops establish poorly • Crop selective

ii. *Land rehabilitation efforts with area exclosures*

In fact, in a country like Ethiopia, where vast degraded ecosystems and a rapidly growing human population occur, and where all livelihood and economic development are to continue to emerge from agriculture and biological resources, the establishment of exclosures is one of the strategies widely used for rapid rehabilitation of degraded lands in the tropics, which is also true in Ethiopia. Area exclosures can be defined as a degraded land that has been excluded from human and livestock interferences, for rehabilitation [17]. The principle is that the two main causes of land degradation are human and animal interference [66]. In order to foster rehabilitation of exclosed areas, in some areas soil and water conservation activities are practiced side by side with exclosures, while in another tree plantings exist. Now days, area exclosure approach is extensively applied in northern Ethiopia to replenish the vast denuded hillsides in line with the need to provide livestock fodder and other tree products. To this effect, excluding areas has been instrumental towards materializing the major goal; achieving conservation based sustainable agriculture. It is also a means to maintain biodiversity in the dry lands of the region within the rural community [60]. These exclosure areas have shown their capacity to restore vegetation, reduce soil erosion and in some areas to improve wildlife resources as well [47].

The main objective of establishing such enclosures is to improve the overall ecological conditions of degraded areas so that they can provide better socioeconomic benefits to the local communities. Establishing enclosures is considered advantageous since it is a quick, cheap and a lenient method for the rehabilitation of degraded lands [15]. Past reforestation and afforestation programs in the degraded areas have often been unsuccessful with no or very low survival of the planted trees. As part of their fight against land degradation, communities have started establishing enclosures, with the hope of preventing further degradation and promoting their re-vegetation. Despite the fact that enclosures have proved instrumental in the re-vegetation and rehabilitation of degraded lands, knowledge on the diversity and status of regeneration of the developing flora as well as the actual and potential socioeconomic benefits [81].

III. Conclusions and Future Directions

a) Conclusions

Throughout the world today, depletion of natural resources is among the major problems facing human beings. The Ethiopian highlands are affected by deforestation and degraded soils, which have eroded the resource base and aggravated the repeated food shortages caused by drought. Although the Highlands occupy 44% of the total area of the country, 95% of the land under crops is located in this area, which is home to 90% of the total population and 75% of livestock. Declining vegetative cover and increased levels of farming on steep slopes have eroded and depleted soils in the area, so that soil degradation is now a widespread environmental problem. Farmers also have to cope with nutrient mining caused by insufficient application of fertilizers, shorter fallow periods and low levels of soil organic matter.

The most frequently cited causes include continuous cropping with short or no fallowing triggered by high population pressure, overgrazing, cultivation of highly inclined and marginal lands without adequate erosion-controlling measures, insufficient drainage of irrigation water and deforestation. World- wide inappropriate agricultural practices account for 28 percent of the degraded soils. Therefore, to minimize or avoid the current and potential undesirable consequences, proper attention must be given to the degraded areas in the country. Rehabilitation strategies of degraded lands improve the overall ecological conditions of degraded areas so that they can provide better socio-economic benefits and environmental services to the local communities. And also increase of plant as well as animal biodiversity with time and after the establishment of rehabilitation measures on degraded lands. In areas where degraded lands and rehabilitation measures have been established, particularly in the northern parts of the country, enclosures are among the green spots with considerable species diversity.

Rehabilitation of degraded lands requires designing economically feasible, socially acceptable and ecologically viable management and conservation strategies. Rehabilitation further improve soil quality, should be carefully evaluated because it may decrease the present support for exclosures in the local population. Exclosures are not only effective in restoring vegetation, but also in improving soil nutrient status and reducing erosion. Reversing the degradation process requires comprehensive and cost effective programme of conservation practices.

b) Future directions

For env'tal rehabilitation to be better attained and sustained in successful way:

- Bottom-up participatory planning, implementation and monitoring by the real stake holders at grassroots level.
- Planning and integrating proper land use, farming practices, and appropriate technologies at grassroots for each specific agro-ecological zone.
- Prepare and implement a national framework for guiding rehabilitation measures on the degraded lands adaptation and mitigation.

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- Invest in new afforestation programs, reforestation, and sustainable management of the remaining forests.
- Implement physical and biological measures to minimize soil loss.
- Increase SOM content by incorporating crop residues and manure into the soil and growing legume cover crops and improve the water holding capacity of the soil by contour ploughing, minimum tillage and adding organic matter;
- Strengthen cooperation among policy makers, NGOs, research institutions, and the media.
- Ensure community participation, especially local people in designing rehabilitation measures.

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Mapping Aquifer Bifurcation Through Integrated Geophysical and Tracer Studies in a Granite Terrain

By Rolland Andrade

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Keywords: dolerite dyke, 2D resistivity tomography, radon counts, faults, litho-stratification.

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I. Introduction

Presently the prime global issues of the 21st century are food security, water scarcity and environmental degradation. Renewable fresh water scarcity remains a problem for millions of people around the world, especially those in arid and semiarid regions. Occurrence of groundwater is mainly in weathered to semi-weathered formations in shallow depths and in fractures/fissures at deeper depths. Exploration and delineation of groundwater aquifer in hard rock terrain is a challenging problem. Surface geophysical investigation(s) are the primary means to delineate and visualize the subsurface complexities through transient or permanent response of measurable physical parameters integrated with the site geological inference. There are numerous geophysical investigation methods adopted for groundwater exploration of which electrical method has shown a wide acceptance and better applicability in groundwater science. Electrical method in concatenation with magnetic, VLF and other investigation methods form a strong tool in delineating subsurface lithology, lineaments and also to decipher conduits for groundwater storage.

In resistivity investigation the selection of site is most important and complex criterion. In usual practice a site is selected based on hydrogeological information gathered over the area and supported by remote sensing data, if available, but there is always a probability that the best location may be away from the selected point. The ground resistivity is related to various geological parameters such as the mineral content, intergranular compaction, porosity, degree of water saturation in the rocks etc. (Dr. Laurent Marescot, 1995). In this manuscript, the author highlights a unique case of a dolerite dyke occupying a fault, bisecting the shallow granite aquifer into two halves during pre-monsoon period. Geophysical investigation(s) in association with geo-hydrological and tracer methods have been attempted in understanding this site specific problem. Tracer studies were carried out at specific location based on interpreted geophysical investigation results and has concurred the presence of fault associated with a Dyke.

II. Study Area

The study area was selected within a watershed basin of ~150 sq km in a semi-arid granite terrain. The prime purpose of the watershed selection in such area was to undertake integrated watershed management and groundwater quality assessment studies. Based on natural resource map & geological mapping, it was confirmed that the geology of the area is basically granite (pink/grey) with numerous dykes and faults signifying high tectonic disturbances during the recent geological past. The drainage pattern of the watershed area is parallel to sub-parallel and is structurally controlled as seen in figure.1.

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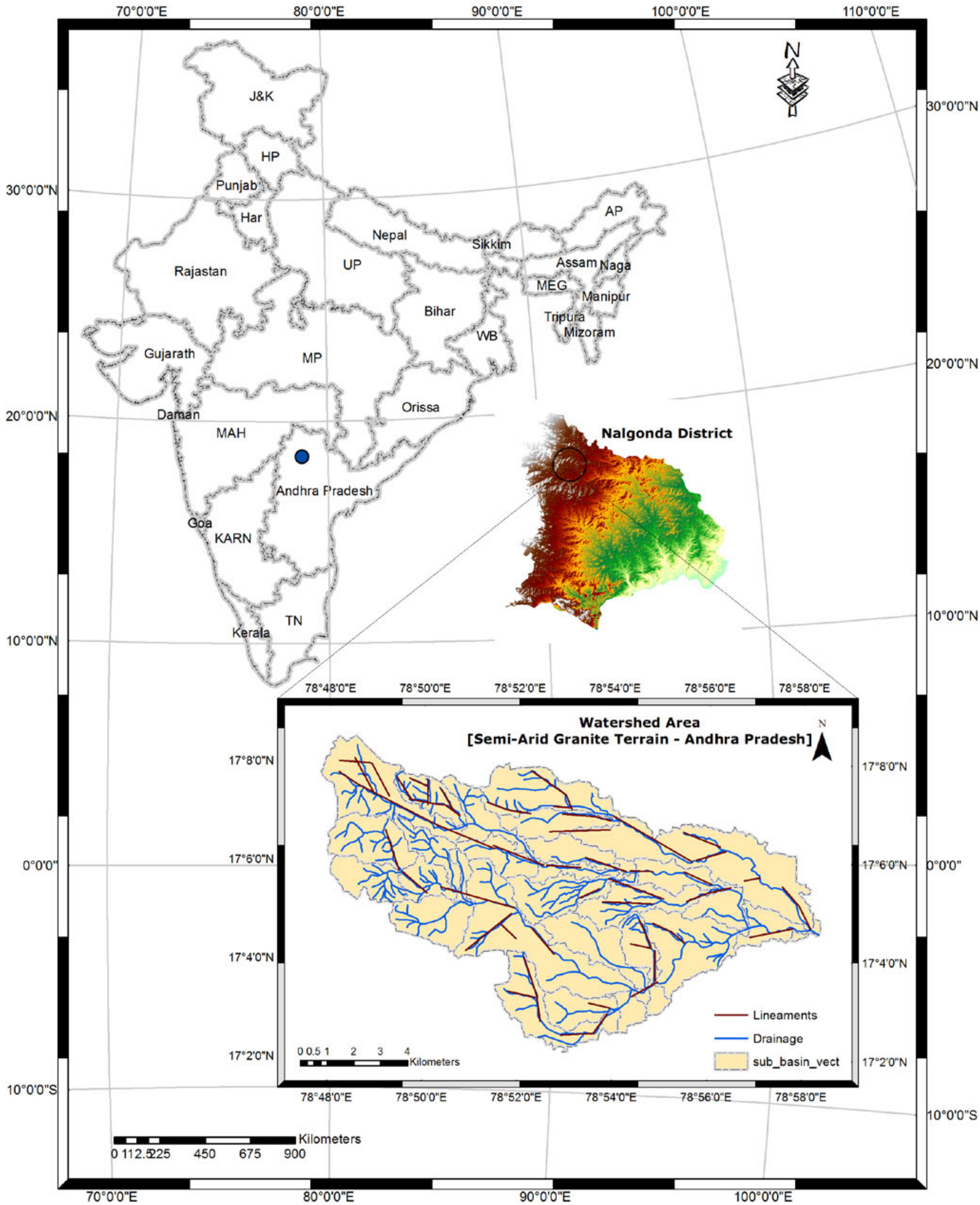

Fig. 1: Watershed area delineated with drainage and lineaments

Physiographycally, the entire watershed area has rugged topography with hill ranges and plains with elevation ranging from 670 m to 400 m A.M.S.L (Above Mean Sea Level). Groundwater in the study area occurs both under phreatic and semi confined conditions in the weathered and fractured horizons. The occurrence of groundwater is confined to shallow to moderate depths. The thickness of the weathered residuum varies widely and ranges between 8 to 20 m and occasionally up to 40 m. Shallow fractured and fissured zones occur beneath the weathered zones down to the depth of 30-75 m bgl.

III. Methodology

Groundwater exploration, aquifer depth determination and site selection for artificial recharge structure like check dam, percolation tank etc. was carried out in the study area, using surface geophysical investigation(s) techniques. Electrical resistivity method, Very Low Frequency (VLF) method, 2D resistivity imaging etc., along with tracer studies were carried out in order to determine the lithological distribution, depth to the basement, presence of faults and emplacement of dyke in the area under study. The basic concept and working principle of these methods are discussed as follow:

a) *Resistivity Measurements*

Resistivity measurements are normally carried out by injecting electric current through two electrodes (C1 and C2), and measuring the resulting voltage difference through electrodes (P1 and P2). The calculated field resistivity value is an "*apparent*" value, which is the resistivity of a heterogeneous medium, which in turn gives variable resistance value for different electrode position and spacing. In order to determine the true resistivity of the subsurface, the measured field value has to be subjected to inversion using computer program. Resistivity surveys are broadly of two types viz. (1) Vertical Electrical Sounding (VES), also known as electrical drilling, or expanding probe. It gives the resistivity behavior of horizontal or near horizontal interfaces occurring at varying depths; and (2) Constant Separation Traversing (CST), also known as electrical profiling or scanning. It gives the lateral variation in electrical conductivity within the subsurface (Rolland Andrade, 2009).

i. *ERT (Electrical Resistivity Tomography)*

2D resistivity imaging (E.R.T) in broad sense is a combination of both electrical profiling and sounding, designed to overcome several constraints raised from independent methods (Dahlin T., 1996; Keller G.V. and Frischknecht F.C., 1966; Griffiths, D.H. and Turnbull, J., 1985). Based on the CVES principle (continuous vertical electric sounding), the electrode arrays combines electrical sounding and electrical profiling together; which results in resistivity values measured both along a line and simultaneously at different depths. Automatic acquisition systems based on CVES make it possible to collect dense data sets, which give a comprehensive description of the ground in two dimensions (2-D). Advantage of 2D resistivity imaging is not only in mapping the sub-surface information of the area in terms of geo-electrical layers but also in generation of reliable information of large dimension. E.R.T provides a true resistivity pseudo-depth section of the subsurface and also resolves the principle of suppression to a greater extent through its data acquisition technique.

b) *Magnetic Survey*

Magnetic survey is to investigate subsurface geology on the basis of the anomalies in the earth's magnetic field resulting from the magnetic properties of the underlying rocks. It measures small, localised variations in the Earth's magnetic field. In general, the magnetic content (susceptibility) of rocks is extremely variable depending on the type of rock and the surrounding environment. The magnetic properties of naturally occurring materials such as magnetic ore bodies and basic intrusive igneous rocks are best identified and mapped by magnetic surveys. It involves the measurement of earth's magnetic field intensity. Typically the total magnetic field and/or vertical magnetic gradient is measured. Measurements of the horizontal or vertical component or horizontal gradient of the magnetic field may also be made (Mariita N.O., 2007). Common causes of magnetic anomalies include dykes, faults and lava flows. Where the rocks have high magnetic susceptibility, the local magnetic field will be strong; where these have low magnetic susceptibility, it will be weaker.

c) *VLF (Very Low Frequency) Survey*

Very Low Frequency (VLF) Electromagnetics is a geophysical ground probing technology that employs VLF signals in the range 15 to 30 kHz, normally transmitted using powerful radio transmitter used in long range communication for navigational system (Nabighian and Macnae, 1991). VLF method relies on transmitted current inducing secondary responses in conductive geologic units. The transmitted signal has horizontal and linearly polarized magnetic and electrical components of the radiowave, in the absence of a subsurface conductor; however, eddy current is generated when the radiowave field passes through a buried conductor, creating a secondary electromagnetic field. VLF is an effective method for detecting long, straight, electrically charged conductors, and it has been used to locate fractures, image subsurface voids, map landfill margins, and to delineate buried conductive utilities.

IV. Field Investigation

Fifteen vertical electrical sounding(s) (VES) with AB/2 50-80 mts and cadastral survey with 1 m interval spacing was carried out from the catchment to the plains, in order to identify suitable sites for drilling of borehole. Based on VES data interpretation results and topographic elevation from cadastral survey, 4 bore

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wells upto a depth of 30-40 mts were drilled. Based on drilling information and geophysical investigation(s) a lithological cross section was prepared as shown in figure 2. The lithology of the area was interpreted based on investigation result(s) was top soil followed by weathered and fractured granite (aquifer zone) underlained by massif granite as basement. A large diameter open (dug) well termed as resource well was executed near to the foothills were the aquifer thickness is more than 20 m. Further, in order to sustain the resource well both in quality and quantity, a number of water harvesting structures were planned on the upstream section of the study area.

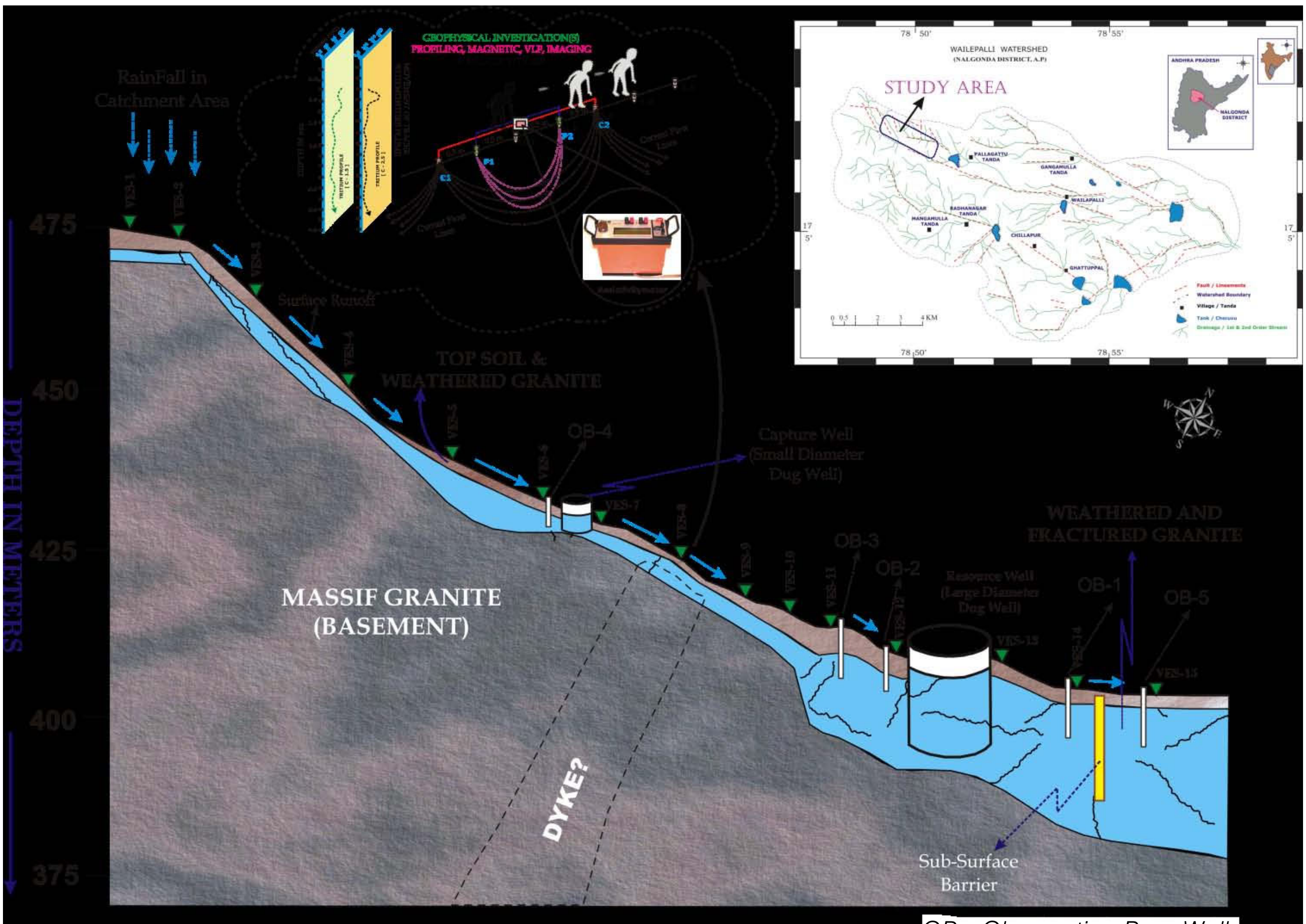

Fig. 2: Lithological cross section with vertical electrical sounding (VES) and bore well location

The aquifer zone which appears to be a single unit with variable thickness from the catchment to the plains is practically segmented / bifurcated into two units between OB-3 and OB-4 as seen in figure 2. Based on water level and other hydro-chemical analysis, it was later established that the aquifer is segmented. In order to authenticate the same, a detailed geophysical and tracer investigation was planned within the selected site as shown under inset in cloud.

In order to have a detailed insight understanding of the watershed area, satellite imageries were analyzed, followed by ground truth, which revealed the presence of a dolerite dyke across the stream course (2nd to 3rd order stream) occupying a fault, trending east-west in the study area. Although the suspected dyke emplacement across the stream course was not visible on the surface, but the same was exposed on the hill slopes along the two flank of the stream. Two observation bore wells OB-3 and OB-4 as mentioned earlier were used to monitor the water level fluctuation for the entire hydrological cycle. During the pre-monsoon season when the water level fluctuates down to a depth below 2 to 2.5 m from the surface, the aquifer acts as two independent systems. Whereas during monsoon and post monsoon season due to rise in regional water table up to the ground surface, the entire aquifer stretch gets interconnected as a single aquifer unit, indicating a hydraulic passage through weathered dyke up to 2 m depth.

In order to authenticate the presence of the suspected fault occupied by the stream and a dyke cutting across; different geophysical methods of investigation were carried out in integration, at the suspected juncture (dyke cutting stream course):

a. Resistivity wenner profiling survey was carried out using DC resistivity meter (Terra Science; Model

TSRM-4/4117) for two different electrode spacing (a=5, 10 and 20 mts.) with station interval of 2 m was carried out perpendicular to the suspected dyke alignment. A resistivity high showing a considerable width of 20-25 m is predominantly seen in all the profile signatures as shown in Figure.3. Investigation was carried out 250 m downstream from observation bore well No.4 (OB-4).

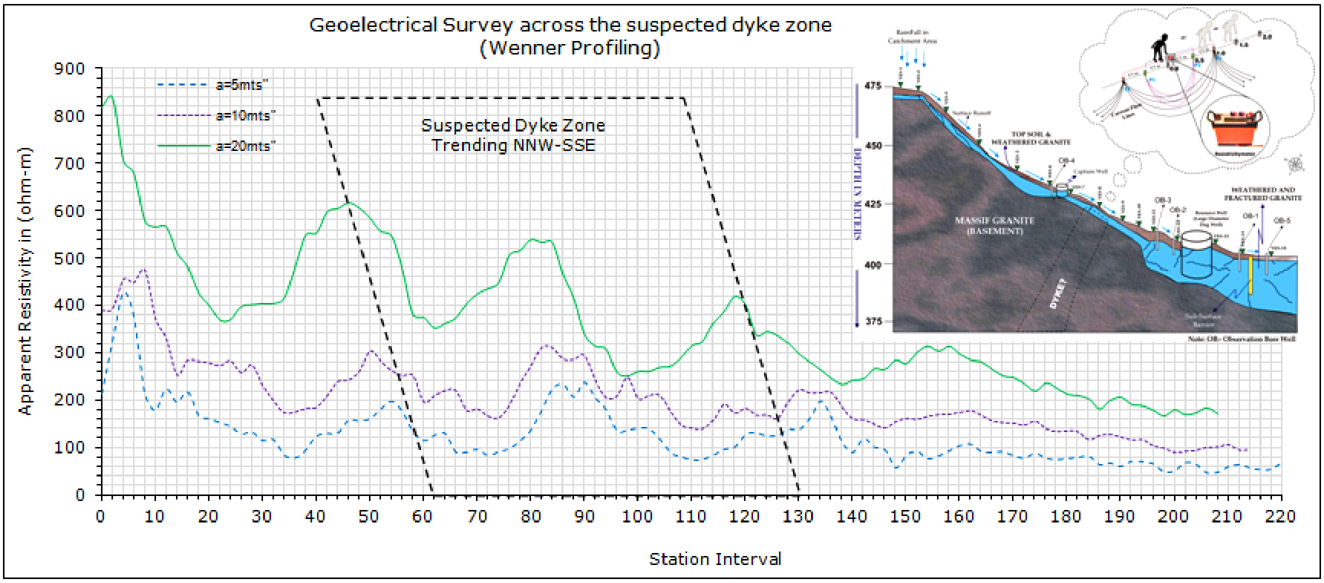

Fig. 3: Resistivity wenner profiling across suspected dyke zone with three electrode spacing(s)

The resistivity signature of wenner profile(s) with spacing a=20, 10 and 5 m, over the suspected buried dyke zone has shown high turbulence in resistivity values ranging from 600 to 70 ohm-m (Ωm). There are three prominent rise and fall in resistivity signature(s) observed within the suspected zone, indicating the sharp flank of the dyke with the host rock and the dyke itself. The resistivity profiling signature across a vertical dyke depends not only upon the resistivity contrast between the dike and the country rock, but also upon the width of the dyke. Usually, in case of resistivity profiling using Wenner configuration, the apparent-resistivity signature has twin peaks shifted towards the center of the dyke for smaller resistivity contrasts. The resistivity signature recorded in the study area, shown in figure 3 appears similar to the theoretical model as mentioned by Robert G. Van No strand & Kenneth L. Cook, 1966. But the signatures lacks in sharpness as that of the theoretical curve, mainly due to the presence of overburden, which comprises of weathered granite (murram), sandy clay and rubbles of weathered dyke.

b. Later on magnetic profiling was carried out along the same profile as that of the resistivity wenner profile with station interval of 2 m. Proton precision magnetometer (Terra-science make) was used to measure the total magnetic field intensity. The area of investigation where the magnetic profiling was carried out was 'magnetically clean' in the sense that the measurements were taken at large distances from buildings or human activity and the emplacement of suspected dyke was in granite (*Felsic* rock type) terrain, which is generally non magnetic in nature.

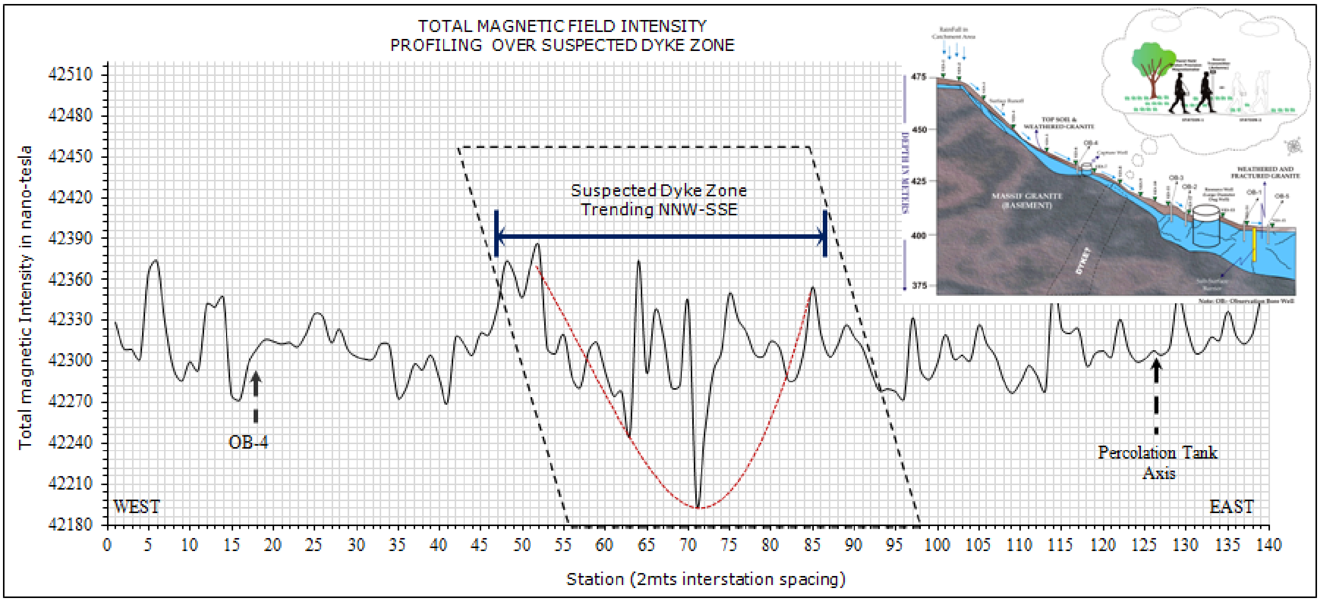

Fig. 4: Total magnetic field intensity across suspected dyke zone

However, no diurnal correction was applied to the measured data, as it took approximately 45 minutes to collect the data all along the profile length. Similar to the observations made in resistivity wenner profiling, the flank of the dyke in contact with the host rock has indicated a drop in intensity of the order 120 nT followed by a sharp rise of 126 nT as shown in figure.4, possibly due to the presence of dolerite dyke itself. Small perturbations are seen in the magnetic signature within the zone of concern, due to isolated dyke boulders and overburden as was the case in resistivity profiling.

c. Similarly VLF (very low frequency) survey was carried out along the same profile line as that of resistivity and magnetic survey, with inter station interval of 2 m. The VLF instrument used was (Scientrex Make) which measures the ellipticity of the magnetic field and also its tilt. Being a profiling tool it is assumed that VLF responds most prominently to the presence of vertical, conductive and shallow bodies (Murali Sabnavis and Patangay N.S., 1998). Generally, the location of the top of the body on a VLF profile may be obtained from a crossover of ellipticity and tilt percentage, signifying a change in the secondary field direction, which is visually seen in the field profile as shown in figure.5. The interpreted results of both wenner resistivity profiling and VLF have shown the presence of shallow, almost vertical contact between two contrasting formations (Granite & Dyke) with distinct resistivity range in the profile.

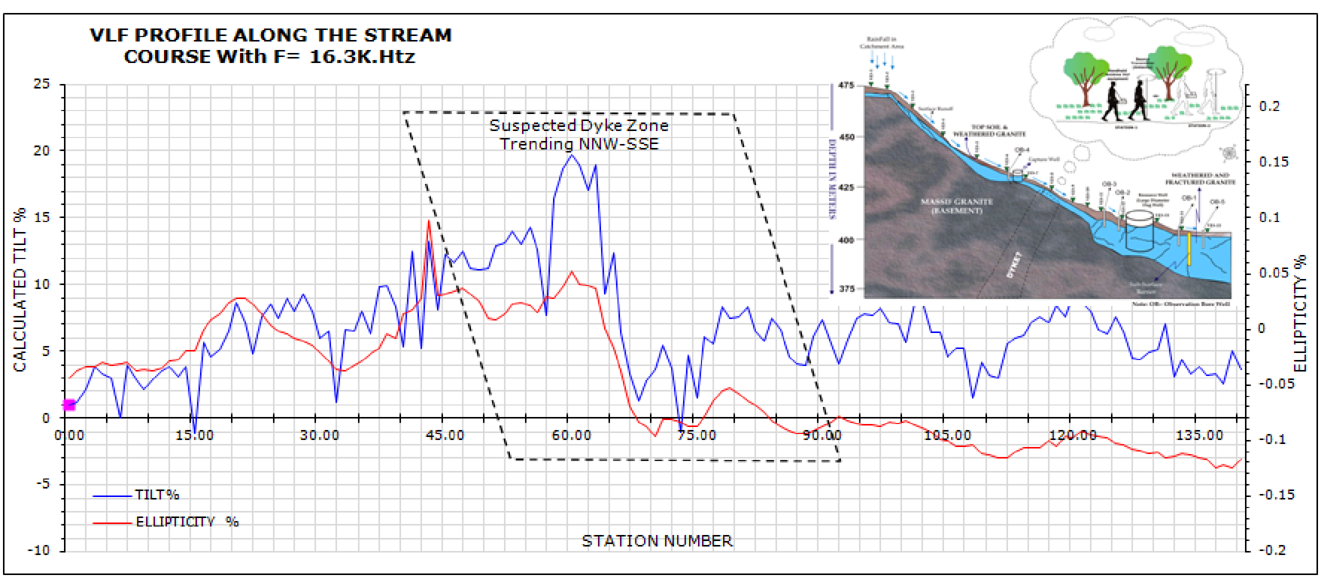

Fig. 5: Very Low Frequency (VLF) profile across suspected dyke zone

d. Later on 2D resistivity imaging was conducted along the stream course in the same alignment as that of other geophysical investigations discussed earlier. Inter-electrode spacing of 2 m was selected during the imaging survey in order to synchronize the true resistivity pseudo section with the results of other geophysical survey(s) carried out along the same profile line. A very distinct demarcation (resistivity contrast 150 ohm-m / 1200 ohm-m) is noticed in the resistivity section, indicating the presence of dyke emplacement along the faulted stream course as shown in figure.6.

Based on all these surface geophysical investigation it was proved that the suspected dyke emplacement in a faulted stream course was in existence. And also that the aquifer system was bifurcated into two during the pre-post monsoon season.

In order to substantiate the above findings with that of tracer studies, an attempt was made. It is generally suspected that natural radon gas emanation is high in granite terrains, which might be more in the vicinity of a fault, fissures or cracks. Hence, radon (tracer) measurements were carried out within the suspected fault cum dyke emplaced zone, and is shown as alpha (α) counts represented in bar chart within the dotted rectangle in the resistivity profile of figure 6.

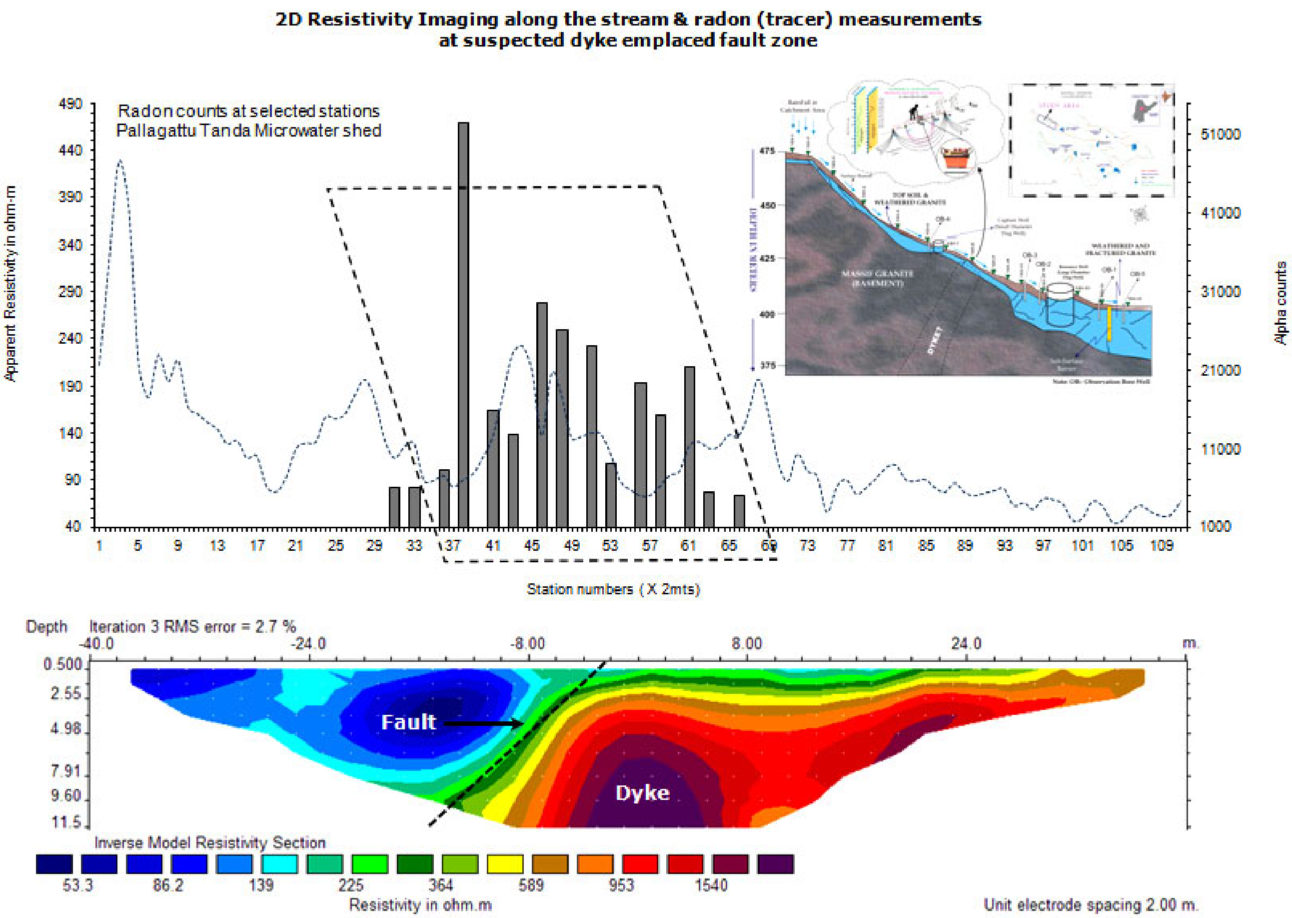

Fig. 6: 2D resistivity pseudo section and Radon (Tracer) results across the suspected dyke

It is clearly depicted in the results that the alpha (α) counts are extremely high within the suspected zone of measurement. Hence all the findings of the previous geophysical and hydrogeological investigations are visually seen in two dimensions in the form of true resistivity pseudo-section and also the weathered dyke upto a depth of 2 to 2.5 m, acting as a hydraulic passage in the monsoon period.

V. Conclusion

From the above discussion, it is evident that numerous attempts were made using different surface geophysical investigation techniques in order to delineate (decipher) the presence of dyke emplacement along a faulted stream course. All the interpreted geophysical results have proved the presence of a dyke cutting the stream course, which is weathered in the shallow depth. Hence, the aquifer (weathered granite), is bisected in this zone into two independent segments in the pre-monsoon season, when the water level drops below 2.5-3.0mts and the same is connected and behaves as a single unit in the post-monsoon season when the water level is shallow (almost the ground level). The finding of the entire study based on geophysical and tracer investigation(s) was useful in adopting suitable strategy for surface runoff and also to artificially recharge the groundwater aquifer system in the study area.

Acknowledgement

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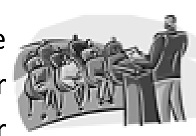

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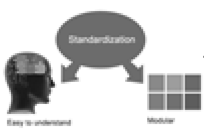

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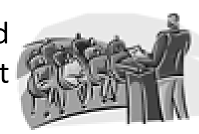

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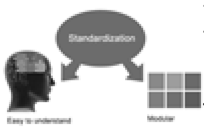

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	A-B	**C-D**	**E-F**
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Introduction	Containing all background details with clear goal and appropriate details, flow specification, no grammar and spelling mistake, well organized sentence and paragraph, 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
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