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Urban Open Space as a Place for Social and Physical Well-being: Narratives from two Different Urban Settings of Kathmandu, Nepal

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ABSTRACT

Increasing population and densification of the cities lead to increasing land value by the high demand of land for housing and other infrastructure developments are the reasons that tend to decreasing open spaces in Kathmandu Valley in general, and Kathmandu Metropolitan City (KMC) in particular. Urban open space has been considered as a place that is accessible to all residents and is important in the urban context as such space provides an opportunity as a place for social interaction, networking, recreation, and various physical health exercises. However, different social and economic contexts of the society reflect different patterns of its uses. Two different urban settings (core urban areas having indigenous dominant population and fringe urban areas having migrants' dominant population) have been taken as a basis for analysis in this paper to look at how different urban societies use open spaces differently. Open spaces are not only important for maintaining urban greenery and beauty for the city but are valued for accumulating social capital and enhancing physical well-being to urban communities. These issues are analyzed through the interpretative research methodology by collecting the data through in-depth interviews, key informants' interviews, informal conversational interviews, and non-participatory observation from two different urban settings of KMC.

1.Introduction

Cities in developing countries reveal complex socio-economic and spatial systems with diverse cultural inhabitants of migrants and non-migrants people residing in different urban settings and this has always been a contention [1]. The debate is seen in the uses of urban public spaces in different urban settings. Urban open space as a public space is well discussed in the literature under urban studies. The idea of urban space is an interesting field of socio-spatial research in the present decade which analyzes open spaces as a place of social, economic, political as well as ecological functions of a city [2-4]. Urban open space is contributing to developing different aspects in urban society including social, physical, cultural, environmental, risk resilience, and psychological benefits [5-7]. Different societies at various times in history have placed more or less attention to the creation and maintenance of public space as it serves as a setting for community activities for collective urban life [8-12]. The collective urban life has turned spaces into places as human interactions with these spaces give meaning. Different communities have developed space as a place reflecting their social, cultural,

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and economic values to create meaning.

As cities are composed up of different social, cultural, and community diversities, those living in an urban area; at least at a community level; share the same space territory and get benefited from the same socio-spatial systems. However, the importance of open space is well explained among urban designers as greenery and recreational places in urban development planning rather it is overlooked in studying the perspectives of social capital and well-being. Urban open space is more than a greenery and recreational place for urban communities and it has a magnitude of potentialities to community people as a shared place for socio-physical and socio-cultural significance [13-14]. Open space contributes to developing social capital [15] and provides an opportunity of earning livelihoods to urban poor [16]. that would enhance the well-being of urban residents.

Public space is a place that is generally open and accessible to all people and is publicly owned or of public use, accessible and enjoyable by all for free and without a profit motive [3,17]. Roads, public squares, parks, *Bahas* (courtyards), *Chautara* (rest places) are typically considered public spaces. Looking at the nature of public open spaces, some open spaces are very limited to public access and some others are having more access to them [18]. Government entities such as public libraries, government offices are open to the public although they tend to have restricted areas. However, institutional open spaces such as hospitals, government offices, schools, and colleges, etc. have more open to the public even though they have different purposes of use.

Urban open spaces play a vital role in the public social life of urban communities. The society acts as a self-organizing public service with a shared space in which experiences and values are created, shared and interactions among the community people established [19-20]. The public place can be a place for sharing feelings, experiences, knowledge and sometimes people get engaged in caring and nurturing at the spaces keep them busy working in their old ages. Physical exercise comes in front while talking about the uses of public open spaces. Such spaces are more important in densely populated cities like KMC as people hardly get open spaces to get engaged in different physical exercises.

This paper will contribute to the academic field of space, place, people, and well-being under urban geography. Such studies are very limited in social science and geographic disciplines. In health science, well-being is simply a multi-faceted construct best described as a state of physical, psychological, and social health [21]. However, this paper explores more than a physical "well-being"; a widely used term in health science, rather analyzes how open spaces are connected to accumulating social capital and enhance well-being for the urban communities. Public urban open spaces find their meaning with human presence and activities, and more than physical role, they are important for creating social interactions among citizens [21,17]. In addition to this, the paper explores public open spaces as Bourdiuen perspectives of social capital [15]. how it contributes to well-being. Bourdieu argues that social capital is "*the aggregate of the actual or potential resources which are linked to possession of a durable network of more or less institutionalized relationships of mutual acquaintance and recognition or the membership in a group*" [15]. Besides, enhancing physical health has also been explored to look at as a form of well-being using the open spaces in different urban settings.

2.The Context

The population of Kathmandu Metropolitan City (KMC) has been increasing rapidly over the last decade. In-migration towards the city is increasing due to the income and employment opportunities, available urban facilities and services, and of course, being the Federal Capital City of Nepal. Kathmandu Valley has been the most common destination of inter-district current migrants as nearly 38% of current migrants go to the central hill, out of which 34% are based in the three districts (Kathmandu, Lalitpur, and Bhaktapur) of Kathmandu Valley [22]. KMC is one of the major destinations of migrants as it has several potentialities to cater to migrants' populations here in different economic sectors. As a result, KMC's population has grown by about 48 percent over the decade (2011-2019), from 975,453 people in 2011 to 1,442,271 people in 2019 [23-24].

Kathmandu has multi-ethnic demography although *Newars,* one of the indigenous groups, still comprise a large segment of the population. Historically known as *Newar* settlement [25]. KMC is the most densely populated city in Nepal with a density of 132.34 people per hectare which is higher compared to the aggregate urban population density of all the cities of Nepal recorded at only 3.77 persons per hectare. There is a growing tendency of decreasing public open spaces having unprecedented urban growth trends in the Kathmandu Valley [26-27] and KMC is at the centre of the valley (Map 1) has its central attraction of in-migrants.

As a piloting study for the Ph.D. project of the author, two different sites from two different urban contexts of KMC were taken as the study areas for empirical analysis in this research paper. With the diversified nature of functions, composition, structures, and physiography, KMC

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poses more dynamic urban landscapes in terms of uses of public open spaces in different urban settings. Two different urban settings (core urban area having a dominant indigenous population and fringe area having dominant migrants' population) were selected for the piloting study. Yatakha Baha from the core urban setting and Suryamukhi Garden (an open space allocated in the planned development area) from the fringe urban area were selected (Map 1). Having a high population density, the core urban area consists of traditional urban settings with typical Newar (indigenous caste/ethnic group of Kathmandu) residents having their typical cultural specialties. Newar communities are more ritual and comparatively rigid on their social and cultural values which are quite different than urban fringe communities in KMC. They have allocated some open spaces for organizing ritual and cultural activities from the pre-historic period. Locally these spaces are called Baha (courtyards- open spaces allocated surroundings the buildings in the community) quite often used for social and cultural activities among the Newar culture.

Similarly, the fringe urban area is having a comparatively low population density compared to the core area. Some areas are having a planned area with dedicated open spaces within it. As these areas are dominated by the migrants' population, they pose a mixed-up of cultures and form a heterogeneous society. These two different sites were selected to compare different urban as well as socio-cultural settings to look at how the open spaces are being used as a place for accumulating social capital and well-being.

3.The Methods and Materials

This research paper is the product of the piloting study for the author's Ph.D. research project in which primary sources of data were collected through different methods and tools. Standardized semi-structured interviews, key informants' interviews, informal conversational interviews, and observation were used to collect the required information. Being a pilot study, two purposive sites were selected for observation to see how people are using open spaces in different socio-cultural settings of the urban area of KMC. This study will help to validate the checklist and questionnaire and further guidance to the researcher to elaborate methodology.

Standardized semi-structured interviews were conducted with 2 respondents from each site (core urban and

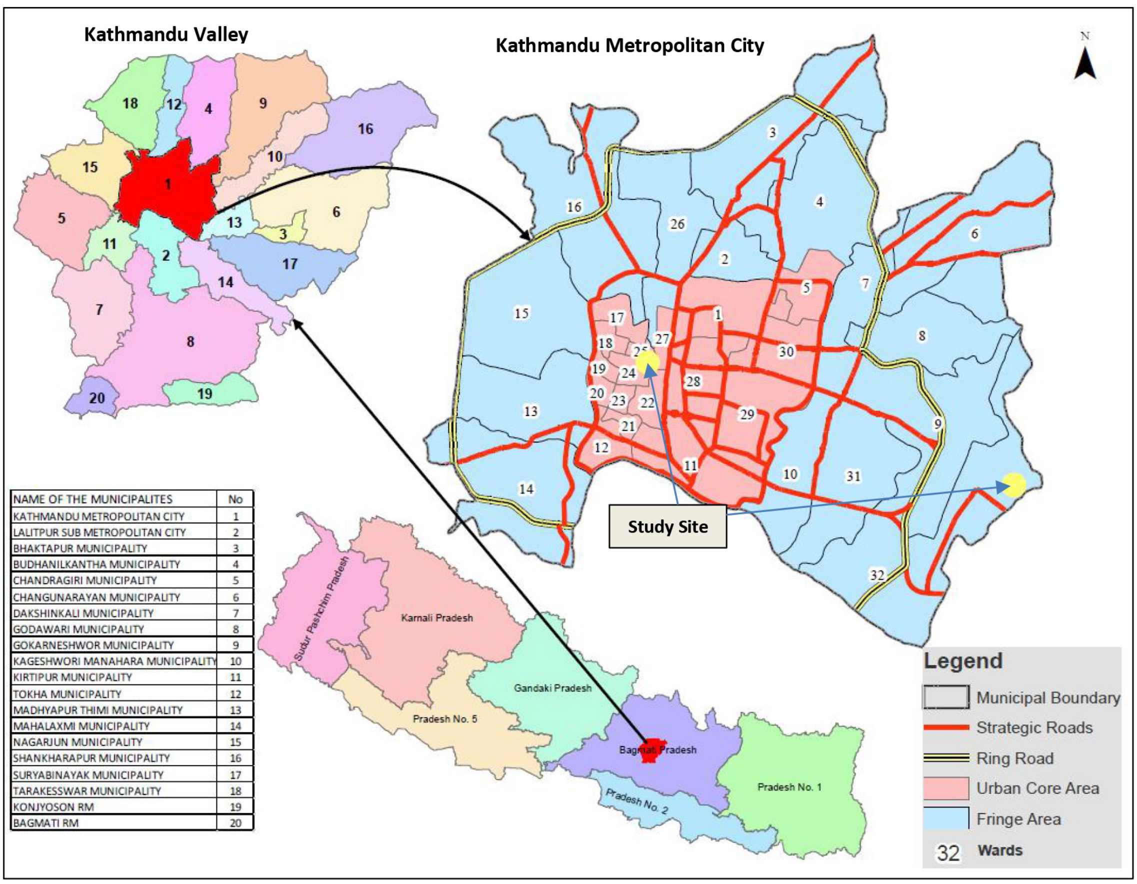

Figure 1. Locational context of the study area

fringe area) which were in-depth in nature. All together 4 in-depth interviews were conducted. Questions were standardized and open-ended to explore data on the uses, functions, and different social and physical activities they accomplish in the open spaces. Two key informants' interviews from each site were conducted to get the information relating to views on the importance, role, functions, and how public open spaces are being used in different social and physical activities for well-being at the community level in different urban settings. The Chairperson of the open space management committee and Yoga Teacher of Evergreen Health Club were interviewed from the urban fringe area whereas a resident and an aged visitor were interviewed from core urban settings as a key informant. Similarly, 2 more informal conversational interviews were also conducted to get insights.

The non-participant observation was used as being an unobtrusive observer to collect information relating to the issue like, why people are visiting the open space, what types of functions the people have been operating at the open space, what kinds of social events organized, how people are using the open spaces over there. Existing use and present functions of the open spaces were thoroughly observed. The observation was made three times a day in consecutive three days regularly on each site to see the different phenomena going on over there. The visitors were thoroughly observed and counted according to their purpose of visit and the activities they perform over there. The observational information was systematically noted down daily as "observation notes" and visitors were counted and get averaged of three consecutive days' participation in different socio-cultural activities.

The collected data then analyzed to look at insights into different contexts in different settings of KMC. Discourse analysis as the method has been done to interpret meaning-making analytical approaches [28-29] to preset urban open space as a place for well-being in two different urban settings of KMC.

4. Result and Discussions

4.1 Narratives from the Indigenous Community

Public open space in the core city, the dominant residence of indigenous communities of KMC and typically known as *Baha* in local dialects of *Newar* communities are successful open space practice of KMC. *Baha* is a type of courtyard found amongst *Newar* communities in KMC with *Newari* Architecture. *Baha* is a Buddhist Monastery and derives its name from the Sanskrit word Bihara, meaning joy or enchantment, and thus, it is a place of religious bliss [27]. The *Bahas* are generally constructed by a family and their descendants reside in it for generations [30]. A community is formed to use and protect the Baha as it is surrounded by the indigenous residents and they have common rights to use them. These *Bahas* are open spaces for the community to use in different socio-cultural activities and other different purposes in that community.

These *Bahas* seem more important for socio-cultural purposes rather than physical and recreational activities. Since the core urban area poses densely populated with the domination of *Newar* communities, they are using the public open spaces as a place for their cultural ceremony (e.g. marriage, *Pashni- the* naming of newly born babies, *Belbibaha*-symbolic marriage of baby girls culturally practiced in *Newar* culture and other religious and cultural *Bhoj-a* type of gatherings for offering the food). Being an indigenous community of Kathmandu, their culture is more typical in the core city and the public open spaces as *Baha* is more common to them. Data shows that there are more than 1363 small to large-sized *Bahas* (Courtyards) in the city core area of Kathmandu [31] which are being used mostly for social and cultural purposes. In the historical past, these open spaces would be used for agriculture associated purposes particularly for grain processing, drying too. Nowadays, as farmland in KMC is almost distinct, such grain processing and drying are almost disappeared. Thus, the use of patterns of such open space has changed over time.

Box 1: Narratives from urban core Area (Yatakha Baha)

In the past, there were farmland within KMC and we used to produce much paddy, wheat and maize. At that time these Bahas were used to dry the grains so that we could preserve the grains longer. All these households had produced grains and this Baha was occupied fully for drying the grains in the seasons (68 years Old woman of Yatakha Baha).

This Baha is our historical asset tied with cultural and religious purposes. All the community members in the past used to use this place as space for Bhoj. In the past there were no party venues as these days do in Kathmandu, and all the community members used this place for offering the Bhoj (63 years community member-Yatakha Baha).

Still these days some families of this community use this Baha as place for offering their Bhoj (Party). We have some typical system of Bhoj to be served in the community for which our ancestor had preserved such spaces in the community (70 years community member- Yatakha Baha).

Looking at the narratives from indigenous residents of urban core areas on the use of public open spaces, different views have been made during the interviews (Box-1). It has been observed that the *Bahas* of the core urban area of KMC were historical assets that used to be protected by community groups mainly for different so-

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cial and cultural activities and grain processing. So, in the past, besides historical and socio-cultural importance, the public open space would be used for crop drying and processing as they used to produce crops on their farmland in and around KMC. Hence, historically the open spaces in the core urban were in diverse uses and also indicates the household's economy of that time. But with time being the communities have been changing the uses of open space for recreational and physical health-enhancing activities as farming activities almost disappeared now. The changes have also been brought about by the social transformation by which party palaces are now replaced the traditional practice of *Bhoj* at public open spaces [27].

4.2 Narratives from the Migrants Community

Box 2: Narratives from fringe urban area (Survaymukhi Garden, Pepsi Planning)

I am living at this community for 20 years with my youngest son and daughter-in-law. My older son and his family are abroad. When I remember them and want to call them abroad, I use to come this place and connected with them. I feel more comfortable talking with them from this place than from home (65 years old man- an informal conversational interviewee).

I visit regularly at this place during the morning and in the evening. I have some close friends who also visit this place regularly and we share our feelings, our experience, life stories and get time pass. This place is not only for time pass of our ages but makes us refreshed hearing other life stories (65 years old man-regular visitor, an informal conversational interviewee).

I am now 92 years old and still able to walk. I used to come at this place twice a day (in the morning and in the evening). I walk, rest and get time pass here for two hours a day. This place has been an important for me to get engaged with community people and sharing my feelings (92 years old Key Informant).

If we look at the uses of public open spaces in the fringe urban areas of KMC, it is more dynamic and very different than that of core areas (indigenous). The public open spaces in the urban fringe area are being used as social and physical well-being for the society. As the residents of the fringe areas are dominantly migrants, they pose more heterogeneity in culture and social diversity. People get gathered and share their personal feelings, ideas, and get connected among the community people in the shared spaces for social interactions, networking, and recreation. They develop social networking through regular interaction, communication, and the sharing of ideas. Social networking is an important phenomenon through interactions, yoga, sports activities that community people are engaging in the public open spaces here (Box:2). The open space has become valued for developing social capital enabling community institutions such as community groups and developing different forms of social networking in society [15].

Box 3: Narratives from urban fringe area (Suryamukhi Garden, Pepsi Planning)

I have been getting physical exercise at this place for 3 years. I personally have found many changes in my physical health since I joined with this team. I was suggested to get regular physical exercises by a Doctor as I had pre-diabetes three years ago. Since I started to get physical exercise with this group, I have managed the diabetes and getting better my physical health. Nowadays, if I missed a day to get exercise, whole day becomes uncomfortable as I feel something missing on that day (48 years lady, local visitors).

On the one hand, the regular group exercise (Evergreen Health Club) has been a very good step for improving our health; on the other hand, it has been a good platform for us in social networking. We are now 20 members in this group and get registered in the municipality forming a committee to act as a social organization. We are planning to contribute to manage street children and single women living in the society (52 years Chairperson of Evergreen Health Club, Pepsi Planning).

One day a member of our committee got ill at home and immediately got admitted at Hospital with the immediate response by our community organization. We have a group in a social network media by which she got immediate treatment which is a social benefit of being a member in this organization (52 years Chairperson of Evergreen Health Club, Pepsi Planning).

I am a regular player at this Badminton court. I am a diabetes patient. Doctor has referred me metformin twice a day and suggested regular exercise. I started playing badminton for 6 months. I have now felt more comfortable and diabetes is under control. Therefore, this open space has been habitual for me in healing the diabetes (A 55 years man-visitor).

I am a medical professional and use to get a regular walk at this place. I also suggest my patients for regular walk daily which helps healing different diseases resulting through busy urban life and hectic daily schedule (40 years medical professional, an informal conversational interviewee).

Moreover, the open spaces are being mostly used in different forms of physical exercise which has great implications for healing the different diseases for younger to old age people. People walk and run, get different physical exercises, and get yoga and meditation at a dedicated public open space in the urban area. Physical exercise is more common in fringe urban areas in KMC as the spaces are comparatively well managed by community groups with greenery and provisions of sports infrastructures over there. People get engaged in different physical exercises such as walk, yoga, group exercises, playing badminton, etc. They have been improving their health on the one hand and developing social capital through social networking and the formation of community groups and organizations in society. Evergreen Health Club is one of the examples of community organizations activated during regular yoga exercise which is now actively getting engaged in different social activities in the society (Box:3). So, open spaces in fringe urban areas in KMC have more dynamics on social and physical aspects of urban life enabling their well-being.

5. Findings

There is a strong argument that a city needs sufficient open spaces not only for regulating spatial urban form but for developing social capital to enabling well-being for the urban communities. The need for public open spaces as a place for well-being has been discussed taking the cases of two different urban social settings. Indigenous *Newar* communities from the core area and migrants' communities from the fringe area of KMC were taken as study cases to compare among the different social settings. Being a piloting study, the present finding is based on the study of two different sites of core and fringe areas of KMC. Looking at the uses of public open spaces in different urban contexts in KMC, the result varies according to the community composition, social dynamics, and cultural practices amongst the communities.

Public open spaces in the cities are heart as they serve urban communities not only for urban beautification but for enhancing their well-being. Developing social capital through community organizations, networking, interactions, communications, and organizing communities' social and cultural events as well as physical health enhancement through sport, run, walk, yoga, meditations, etc. are the forms of well-being. Result reveals that there were 152 visitors encountered at the selected open space from core urban open space and 290 visitors at the selected open space in the fringe urban area. The data reveals that different urban settings have different uses of open spaces in Kathmandu① (Table:1). Observation is that visitors in the core area have been using public open spaces for cultural and religious activities (36.2%), organizing community meetings (21.1%), walk/run/yoga and exercises (18.4%), recreational and entertainment (14.5%) and sports (9.9%). Similarly, people from the fringe area visit open space for organizing community meetings (6.9%), walk, run and yoga (41.4%) recreation and entertainment (31%), sports (20.7%). It reveals that there are different patterns of visiting for the use of open spaces in different urban settings in the city. However, all their visits are associated with enhancing social capital and improving their health for well-being purposes.

Table 1. Activities observed at the urban open space

S.No.	Used for	Core Area	Percent	Fringe Area	Percent
1	Cultural and religious activities	55	36.2	-	-
2	Organizing community events (meetings)	32	21.1	20	6.9
3	Walk/run/Yoga and exercises	28	18.4	120	41.4
4	Recreation/ entertainment	22	14.5	90	31.0
5	Sport related (Badminton)	15	9.9	60	20.7
	Total	**152**	**100**	**290**	**100**

Source: Field Observation, 2020

Empirical evidence also suggests that open spaces and parks in urban areas serve to improve the physical, social and psychological health of the city as they enhance not only the city's beauty but provide spaces for social interaction and recreation and contribute to the livability of a city, and serve critical purposes of evacuation during disasters [32-33]. The central focus of discussion in this paper is on exploring the importance of public open spaces as a place for well-being such as enabling social capital and enhancing physical health. But the author also intends to discuss the importance of public open spaces for disaster risk management in another paper.

People in historic core urban settings in KMC have been using open spaces for cultural and religious purposes as they have allocated *Baha* with *Newari* Architecture. Historically the *Bahas* were used religious and cultural activities along with drying and processing the grains as much area in Kathmandu was dominantly used in farming. However, with rapidly growing urbanization and the disappearing of the cultivable land with increasing land value and land fragmentation, urban expansion rapidly took place, and uses of such *Bahas* are getting changed. Nowadays, cultivation within the KMC is almost extinct and the built-up area dominated the land use/cover [26-27]. These *Bahas* are now been mostly used in cultural activities in different social and cultural activities of the communities functioning to develop well-being developing social capital.

As the different stories of urban fringe areas of KMC

① *The data presents the number of visitors per day encountered at the selected sites during the field observation. Three times a day (morning, afternoon and evening) was visited to observe the details of visitors' activities and averaged to get the total number of three consecutive days visitors' data. The number of visitors may vary according to the seasons and the cultural and ritual seasons of the indigenous Newar community because the frequency of cultural and religious activities is more in some specific seasons of Newar communities.*

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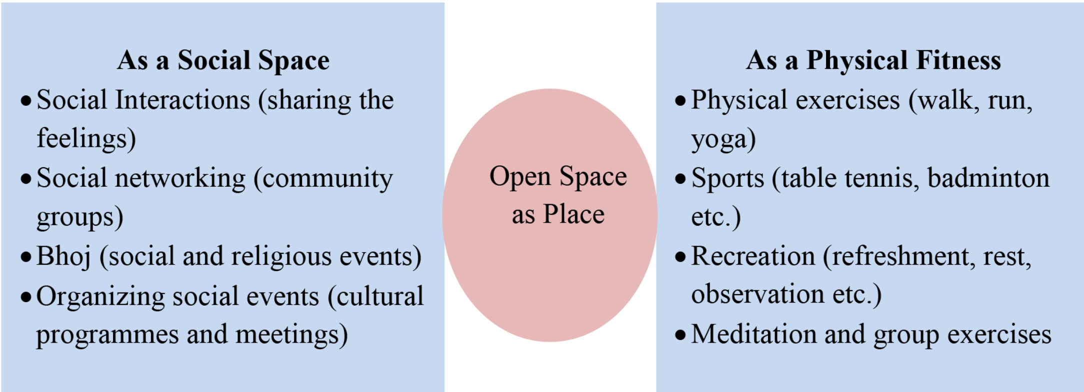

Figure 2. Urban open space as place for social and physical well-being

explained above were quite different than that of the core urban area, the uses of open space are more dynamics there. This dynamism may appear due to the social composition as the urban fringe areas of KMC is more heterogonous having mixed up of different cultures of migrants' population. They were mostly migrated from other districts and have different ethnicities and cultures [25]. Migrants communities usually organize social and cultural activities in the party venues/palaces. But they have been using the open spaces for more social as community networking and as improving their physical health through different physical exercises. However, the traditional community uses open spaces more on organizing cultural events and *Bhoj* and less on social interaction and physical exercises as these spaces are less likely to appropriate for physical exercises (Table:1). Public open space has been observed as a place for well-being contributing as a social space and physical fitness as shown in the following figure (Figure 2);

6. Conclusions

Urban open space in the study of socio-spatial perspectives is getting its pace in the recent academic discourse worldwide. But still, it is less studied in the Geographic discipline in Nepal to analyze how space as a place is functioning in enabling social and community well-being. The public open spaces in Kathmandu are decreasing with the increasing expansion of the built-up area. The historically preserved *Bahas* is a successful open space practice at the community level in the core urban areas. In the past, the *Bahas* in the core urban areas were in extensive use for religious and cultural purposes and for processing the grains as the households had been involved in agricultural-related works. The uses of open spaces now have changed over time with social transformation, and there are also different patterns in the uses of open spaces in the core and fringe urban areas representing different social and cultural settings. In the core urban context with the indigenous *Newar* communities have been using open spaces more culturally which is quite different in the fringe urban contexts. In the fringe urban context, community people have been using open spaces for developing social capital and enhancing physical health well-being. This means urban open spaces are functioning as a place that is more linked to the social dynamics of society. It has been found that the fringe urban context, being a heterogeneous social composition is more dynamics for using open spaces than that of the core urban settings. They have been using open space for developing social capital and enhancing health well-being.

Hence, it is concluded that open spaces are needed in the urban context not only for maintaining greenery and recreational place in the built environment but it has more important for accumulating social capital and enhancing physical health in both urban settings. The case studied urban open spaces as a place for well-being in both settings have highly determined by social and cultural contexts. Accumulation of social capital and well-being is associated with social and cultural contexts and vary according to social settings. The more heterogeneous the society, the more dynamics it performs, and the less heterogeneous the society, the less likely the dynamism it poses in enabling social and physical well-being.

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ARTICLE

Impacts of Climate Variability on Sustainable Agriculture in Imo State, Nigeria

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ABSTRACT

Rainfall and Temperature are important factors in agriculture especially in Nigeria where rain-fed agriculture is practiced extensively and agriculture contributes to food security and provides employment for urban and rural dwellers. Therefore, climate variability represents a major danger to agriculture by modifying the rainfall and temperature pattern, thereby resulting to a big peril in the sustainability of agriculture. This is the reason all countries of the world are concerned about the effects of climate variability on agriculture. This work therefore, examined the impact of climate variability on rainfall and temperature in Imo State, South Eastern Nigeria. The rainfall and temperature data were gotten from Nigerian Meteorological Agency (NIMET) for a period of 30 years which was analyzed by using descriptive statistics, decadal distribution, trend graph anomalies and 5 year moving average. The analysis showed increasing trend pattern in yearly maximum, minimum temperature and decrease in annual rainfall, The third order polynomial trend shows a decrease in the anomaly of annual mean rainfall (y = -0.0002x4) and a persistent increase in the mean temperature anomaly especially in the second decade (1996-2007).The discoveries show that there is a notable variability in temperature and rainfall pattern which revealed an increase in temperature and decrease in annual rainfall. This calls for serious attention as people in this part of Nigeria critically depend on rainfall for agricultural practices. It is recommended that government should support the agricultural sector by providing mechanized farming systems such as irrigation and drilling of water borehole in farm sites for agriculture, especially for the rural farmers and create awareness to the farmers on recent trends in climate issues to achieve sustainable agriculture.

1. Introduction

Agriculture is an important sector in the economy of a nation. In recent times, so many countries in the world are focusing and investing in agriculture because of its importance by encouraging and granting loans to youth to be involved in agricultural production and of course in Nigeria several private enterprises', NGOs are partnering with the

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government to bring a revolution in agriculture. If agricultural production increases it will reduce unemployment by creating jobs, increase the availability of food, improve the economy of the nation and agricultural sustainability can be achieved. The greater part of the individuals in Imo State engages in agricultural activities and trading of agricultural product. Imo state is significantly known for crops such as, cassava, maize, cocoyam and vegetables additionally the intercropping system of agriculture is practiced with yam, cassava, cocoyam, and maize as the major arable crops, while oil palm, banana/plantain and citrus are the major permanent crops. The inhabitants of Imo state are predominantly farmers producing food crops such as cassava, yam, and maize [1]. The impact of climate variability on agricultural production has been connected to global warming and the resulting change in climate is projected to aggravate a decrease in agricultural production in light of the fact that global warming might incite unfavorable climatic condition for agricultural practice [2]. Therefore, sustainable agricultural production system is significant and it includes a decent way to deal with food production that will guarantee consistent increase in productivity without undermining the chances of generations to come. This will include production practices that guarantee environmental conservation and insignificant aggravation to the natural eco support system because agriculture is imperative to the economy and people of a nation. Some countries of the sub-Saharan Africa are highly vulnerable to the impacts of climate change this is because agricultural production in most sub-Saharan African countries is dependent on weather and climate, unlike some developed countries that practice mechanized agriculture where several agricultural activities are supported mechanically [2-3].

2. Literature Appraisal

Climate variability has impacted a lot of sectors in the economy of a nation including agriculture. Its impact on agriculture is visible especially among those nations that depend on climate variables (such as temperature, rainfall for growth and agricultural sustainability. This is the major reason variability on rainfall and temperature is liable to affect agriculture. Variability is an inevitable aspect of climate and variability spans across many time and space scales and it includes occurrences such as El Niño/La Niña, droughts, multi-year, multi-decade, and multi-century changes or fluctuations in precipitation and temperature patterns. Climate in a thin perspective is defined as the "average weather condition of a place", or better defined, as the statistical measurement of the mean and variability of important number of specific variables (such as precipitation, temperature or wind) over a timeframe going from months to thousands or millions of years. The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization. Climate from a more extensive perspective is the state, including a statistical description of the climate system [4].

Climate Variability is defined as the variations in the mean state and other statistics of the climate on all temporal and spatial scales, far off individual weather events. The expression "Climate Variability" is frequently used to denote deviations of climatic statistics over a specified timeframe (e.g. a month, season or year) when contrasted with long-term statistics for a similar period of calendar and is computed by these deviations, which are typically called anomalies [4]. In another definition Variability might happen due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external factors: external variability [5]. Climate originates from the reallocation and changes in the measure of energy around the world, which lead to changes in pressure, temperature and other climate variables. The amount and movement of energy result from a huge number of factors, including those external to earth's framework (for example the measure of radiation produced from the sun) and internal ((for example volcanic action obstructing solar radiation from reaching the earth's surface). In this way, the weather at any given place and time will be impacted by various climate variability factors [5].

Agriculture is susceptible to harsh weather conditions which can be as a result of climate variability. This can influence agricultural production and sustainability and ultimately affects the economy of a nation. In the tropical environment where rain-fed agriculture, is very important for agricultural production, the onset and cessation of the rains determine the traditional practices of farmers, for example, land readiness, crop assortment choice and planting to harvesting [6]. New techniques have been initiated in some nations of the world to ameliorate the variable nature of climate variable such as irrigation, improved seedlings, crop varieties and other agronomic management procedures to help support the system towards a better food production. Notwithstanding massive advancements in agricultural production technology, weather and climate actually assume an outstanding part in affecting agricultural production across the world especially in Africa [7-9]. Specifically, under rain-fed conditions the production capability of a crop relies upon the climatic conditions of an area [10]. Rainfall is very important to agriculture especially in the tropics because of the relatively high temperature all through the year with a persistently high rate of evaporation [11]. Rainfall not just

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decides the length of the growing season of any location [12] but on the other hand is imperative to planting, germination and the prosperity of yield development [13]. It has also been noticed that growth processes resulting to yield in agricultural crops can be slowed down due to irregular nature of rainfall even in wet season [14].

In Imo state several research works has been carried out on climate variability /climate Change impact on agricultural and findings shows that variability in rainfall and temperature has great impact on agricultural production. Rainfall variability in Imo state contributes to the high variations recorded in the productivity and productivity efficiency of the major food crops such as maize and cassava and a decline in crop yield was also observed. [15-16]. It is a practice in the study area that the onset of the rains harmonizes with the time of land preparation, planting and germination in the agricultural schedule, especially under rain-fed agricultural practice. The resultant moisture deficiency emerging from the declining trends of rainfall could be aggravated by the high temperatures [17], which are typically connected with the onset of the wet season in addition to high evapo-transpiration resulting essentially from high temperatures. This is further convoluted with the regular drought incidences which characterize the planting season in the forest belt [13] where the south eastern region of Nigeria is found. The increasing mean maximum temperature in the last two decade after 1990's gave a steady variation in rainfall, length of humid period, length of growing period and the onsets of rainfall with noticeable effect, development and growth of crop yield [18-19]. Climate variability therefore give rise to one of the greatest hindrance to the accomplishment of food security and poverty reduction in the region as both are interrelated processes. It was assumed in this study that the fluctuations in rainfall and temperature regimes are the basic climatic parameters responsible for climate variability over Imo State of Nigeria, as this is the situation in different parts of the world. It is therefore on this premise that this paper focused on climate variability on growing season rainfall and temperature, its implication towards sustainable agriculture in Imo State Nigeria

3. Research Methods

3.1 Overview of the Study Area

Imo State is located between latitude 4°45′N and 7°15′N and longitude 6°50′E and 7°25′E, with an area of about 5100 km2. It lies within the humid tropics and is generally characterized by a high surface air temperature regime year-round. Mean minimum temperature is 23.5°C, mean maximum temperature is 32.3 ºC and mean temperature is 27.9 ºC [20]. Two seasons, wet and dry, are observed in the year, the rainy season which begin in April to October, while the dry season ranges from November to March. Figure 1 shows the location of Imo State.

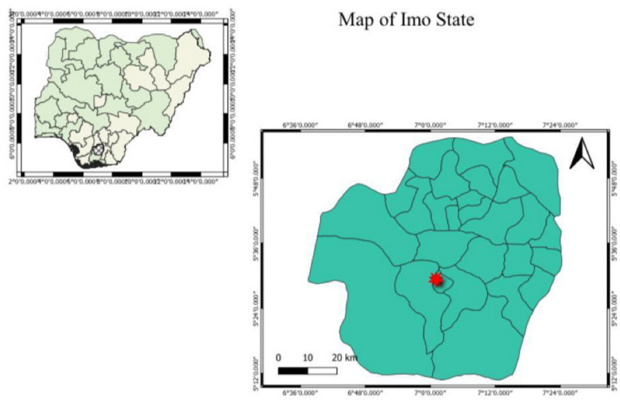

Figure 1. Map of Imo State

3.2 Research Database

The secondary data were the monthly rainfall and temperature data of Imo State in South-Eastern Nigeria for a period of 30 years (1987-2016) which was collected from the Federal Meteorological Services Oshodi in Lagos State. The monthly rainfall and temperature data collected were further converted to annual values. From these values we derived the monthly, annual, decadal rainfall and temperature averages, anomalies, trends, 5 year moving average obtained were used to determine the variability of rainfall and temperature in the study area

4. Results and Discussion

4.1 The Distribution of Rainfall and Temperature

Rainfall and Temperature distribution in Imo State, shows the basic properties of all the variables in this study and the mean monthly and annual rainfall totals, mean temperature, minimum, maximum temperature for the period of study (1987-2016).

(1) Mean monthly rainfall totals

The mean monthly rainfall (Table 1) shows an overall change in the pattern of monthly rainfall, the month of August has the highest rainfall with mean of 377mm. While, the month with the lowest rainfall is December with mean of 17.44mm this shows an overall change in the monthly rainfall pattern.

Table 1. Mean monthly rainfall in Imo State (1987-2016)

Months	Rainfall (mm)
January	20.97
February	43.01
March	91.73
April	174.06
May	262.06
June	318.38
July	373.29
August	377.21
September	373.94
October	259.09
November	54.64
December	17.44

(2) The Mean Monthly Maximum, Minimum and Mean Temperature in Imo State

Maximum Temperature:

The mean monthly maximum temperature (Table 2) shows that, the month with the highest maximum temperature in Imo State is February with mean of 35ºC while the month with the lowest maximum temperature is 29ºC in July. The results reveal that the peak of maximum temperature is during the dry season in February.

Minimum Temperature:

The mean monthly minimum temperature (Table 2) shows that, the mean monthly highest minimum temperature is march with 24ºC while the month with the lowest value of minimum temperature is January with mean as 23ºC.

Mean Temperature:

The mean monthly temperature results (Table 2) indicates that mean monthly temperature was highest in February with 29.7 ºC while the lowest mean Temperature falls in the month of July with the mean as 26.25 ºC

The Minimum, Maximum and Mean Temperature is highest in February and March which is the peak of the dry season.

4.1.2 The Annual Rainfall Pattern

(1) Annual Rainfall

The total annual rainfall across the state of study for the period of study (1987-2016) (Table 3) shows that, the years with the most highest rainfall totals in Imo State is 2009 and 1997 with 2916.7mm and 2891.4mm, respectively, while the years with the lowest rainfall totals is 1998 and 2004 with rainfall totals as 1641.5mm and 1777.8mm.This show a decrease in rainfall.

Table 3. Annual rainfall totals in Imo State (1987-2016)

	Year	Rainfall Totals (mm)
Annual highest rainfall	1997	2891.4mm
	2009	2916.7mm
Annual lowest rainfall	1998	1641.5mm
	2004	1777.8mm

(2) The mean annual maximum, minimum & mean temperature

The mean maximum annual temperature (Table 4) shows that, the year with the highest Maximum Temperature in Imo State is 2010 with Temperature as 33 ºC while the year with the lowest maximum temperature is 1991 with temperature as 32 ºC.

Table 2. Mean monthly temperature in Imo State from 1987-2016 in ºC

States	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Lowest	Highest
Max	33.91	35.16	34.30	33.41	32.34	30.97	29.42	29.50	30.42	31.29	33.02	29.42 (July)	35.16 (Feb)
Min	22.83	24.32	24.48	24.32	23.85	23.45	23.07	23.03	23.21	23.23	23.70	22.83 (Jan)	24.48 (Mar)
Mean	28.37	29.74	29.39	28.87	28.09	27.21	26.25	26.27	26.81	27.26	28.36	26.25 (July)	29.74 (Feb)

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The mean annual minimum temperature (Table 4) shows that, the year with the highest minimum Temperature is 2010 with Temperature as 25 ºC while the year with the lowest minimum temperature is 1994 with temperature as 22.ºC.

The year with the highest mean temperature (Table 4) is 2010 with mean temperature as 28.9 ºC while the year with the lowest mean temperature is 1994 with mean temperature as 27 ºC. The results show that Temperature is on the increase in Imo State.

Table 4. Annual highest & lowest maximum temperature in Imo State (1987-2016) in ºC

	Highest /year	Lowest /year
Max Temperature	33.21 / (2010)	31.6 / (1991)
Min Temperature	24.6 / (2010)	22.3/ (1994)
Mean Temperature	28.9 / (2010)	27.0 / (1994)

4.1.3 The Decadal Distribution of Rainfall Totals, Minimum, Maximum, and Mean Temperature (ºC)

The decadal distribution of rainfall totals, maximum, minimum and mean temperature (ºC) is represented as follows: The first decade is from 1987 to 1996, second decade is1997 to 2006 and the third decade are from 2007 to 2016.

(1) Decadal distribution of Rainfall totals

The results in table 5 shows that Imo State has the highest rainfall totals in the first decade (1987-1986) with 2526.2, while the decade with the lowest rainfall is the third (2007-2016) with rainfall totals as 2278.7 which is a decrease in rainfall. This shows that the state is experiencing a decrease in rainfall.

(2) Decadal distribution of maximum, minimum and mean temperature (ºC)

The results in table 5 shows the decade with the highest maximum temperature is the third decade (2007-2016) with maximum temperature as 32.5 ºC while the decade with the lowest minimum temperature is the first decade (1987-1986) with 23.1 ºC. The third decade mean temperature is highest with mean temperature as 28 ºC while the lowest mean temperature is the first decade experienced the as 27.5. ºC this result shows that there is an increase in Temperature, if temperature continues to increase; it shows that the environment is becoming warmer and this is not favorable for agriculture

Table 5. The decadal distribution of rainfall (mm), maximum, minimum and mean temperature (ºC) (1987-2016.)

	Rainfall (mm)	Minimum Temperature (ºC)	Maximum Temperature (ºC)	Mean Temperature (ºC)
1987-1996	2526.2	23.07	31.94	27.5
1997-2006	2292.6	23.84	32.45	28.1
2007-2016	2278.7	23.69	32.47	28.1

4.2 Annual Rainfall Trend for the Period of Study (1987-2016).

The Rainfall Trend in Imo state (Figure 1) shows that rainfall fluctuated greatly, but with a downward trend of -1.1255x value per year which is a decrease in rainfall

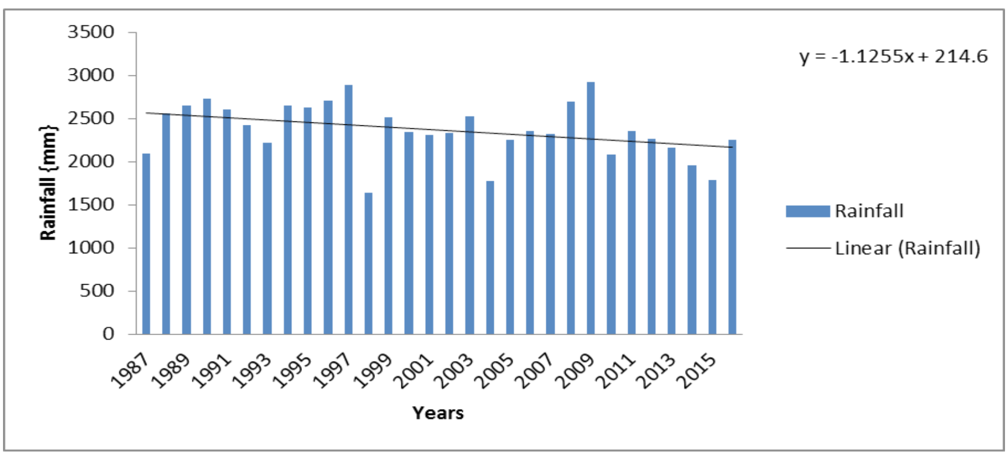

Figure 1. The annual rainfall trend in Imo State (1987-2016)

observed during the period of Study, with highest rainfall in 2009 with 243.06mm values and the lowest rainfall was in 1998, with 136.79mm values. This shows that rainfall is reducing in Imo State and if it persists, it will not favor agricultural production because the farmers in the state depend on rainfall for their agricultural practice.

4.3 The Maximum, Minimum and Mean Temperature Annual Trend Analysis Result for the Period of Study (1987-2016).

The maximum temperature (Figure 2) fluctuated greatly and it shows an increasing trend. The highest temperature is in 2010 and the value is 33 ºC while lowest temperature is 1991 and the value is 31. ºC, also 2011 with the value of 32 ºC. The trend line shows that it is positive the value of 0.0215x value per year, which is show an increase in maximum temperature, while the minimum temperature (Figure 3) shows that it fluctuated greatly too, with a positive trend, and highest temperature in 2010 and the value is 25 ºC while the lowest value is 22 ºC in 1994 and 23ºC in 2011. There is a positive trend of 0.0243x value per year; this shows an increase in minimum temperature.

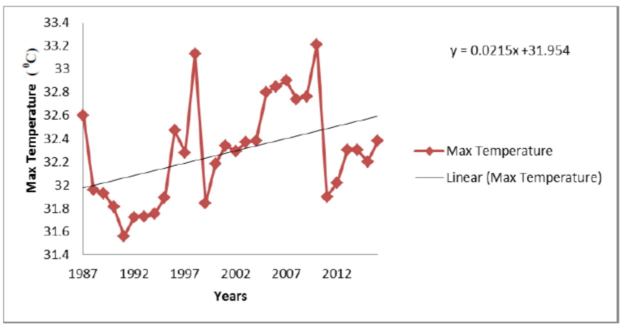

Figure 2. The annual trend of maximum temperature of Imo State (1987-2016)

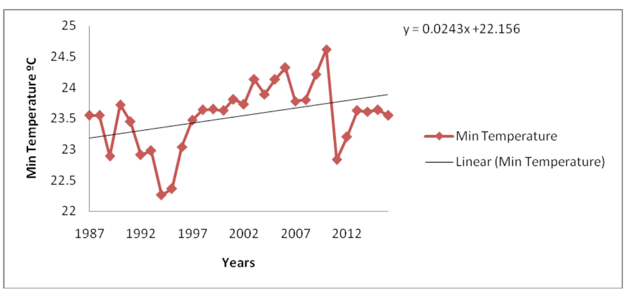

Figure 3. The annual trend of minimum temperature of Imo State (1987-2016)

The trend analysis for mean temperature (Figure 4) shows a great fluctuation with a positive trend and highest temperature in 2010 and has the value of 29 ºC and lowest temperature is in 2011 and has the value of 26ºC. This is a positive trend with a trend of 0.0151x value per year. This shows an increase in mean temperature and coincidentally, minimum, maximum and mean temperature was highest in 2010. This marked 2010 as the hottest year for the study period. This result of minimum, maximum and mean temperature shows variability and increase in temperature, if this temperature continues to increase in the state, it's likely to affect agricultural production and drought incidence in the state.

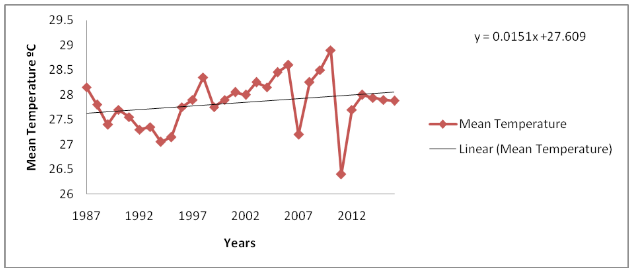

Figure 4. The annual mean temperature trend of Imo State (1987-2016)

4.4 A 5 Year Moving Averages for Rainfall and Temperature in Imo State (1987-2016)

The linear regression trend and 5-year moving average line to the annual rainfall and temperature observation data. The idea of moving averages depends on the possibility that any enormous sporadic parts of time series at any point in time will have a less significant impact on the trend. So, moving average brings a smothering effect on the graph to smooth out short-term fluctuations and feature longer-term cycles or trends. The moving averages for rainfall (Figure 5) shows an increasing trend before 2009 and after 2009 a decreasing trend started and 2008 has the highest peak in rainfall while 2015 has the lowest point while the moving average for temperature (Figure 6) shows that temperature was lowest in 1996 and 2000 temperature started increasing. The attributes of rainfall and temperature changes during those years might be due to countless reasons particularly climate change/ climate variability and when a place experiences a decrease in rainfall and increase in temperature especially in a rain fed environment, most likely would greatly affect agricultural production.

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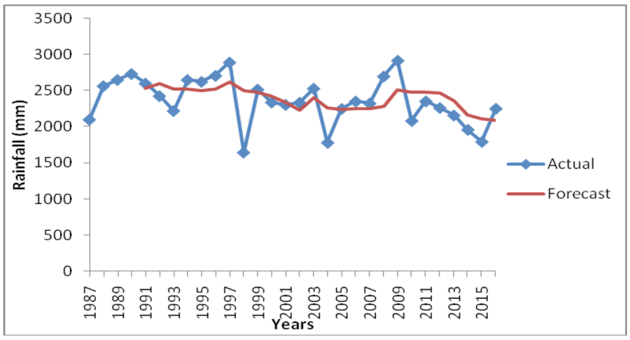

Figure 5. A 5-year moving averages for Rainfall in Imo State (1987-2016)

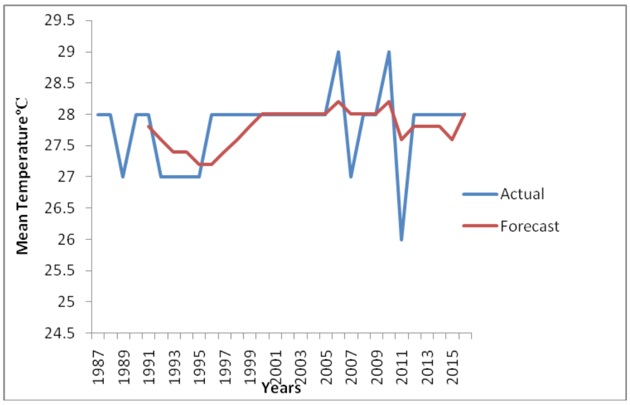

Figure 6. A 5- year moving averages for mean temperature in Imo State (1987-2016)

4.5 The Trend Anomalies of Mean Annual Temperature and Rainfall in Imo State from 1987-2016

(1)Temperature

The annual mean temperature trend anomalies from 1987 to 2016 in Imo State is shown in figure 7. The third order polynomial result depicts a declining trend from 1988 and in 1996 the trend started to increase and towards 2014 it experienced a decline. The Mean temperature was below the mean between 1987 and 1999 (13 years) and above the mean for 14 years (2000-2013) before declining in 2014, this shows variability in Temperature and it is increasing, and a gradual decrease from 2014 which indicate a decrease in temperature. The third order polynomial result shows temperature variability and warming climate which shows that annual mean temperature anomalies have been increasing with time but with a recovery tendency. The discoveries in this work are identified with studies done in Nigeria, which have also demonstrated various times of warming and cooling stages over the last century [21-23].

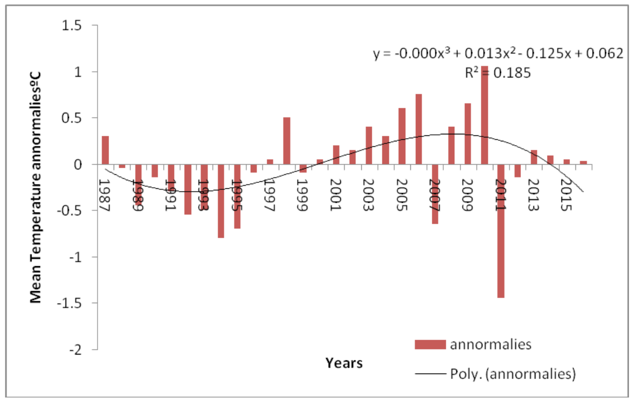

Figure 7. The anomalies of mean annual temperature over Imo State (1987-2016)

(2)Rainfall

The third order polynomial showed indicated that the annual rainfall anomalies in Imo State (figure 8) experienced a decreasing trend. There was an increase in rainfall 1987-1997 and a decrease from 1998 till 2016 with slight variability in the trend. The state might be at the risk of facing a drought if rainfall continues to decrease. This is accordance with the report of [24] that greater rainfall variability in semi-arid Africa will upset endeavors to improve food security combat malnourishment in Nigeria [21] and in Imo state a decrease in rainfall is observed, so the need for alternative source of water to support agricultural such as irrigation farming is very important for agricultural sustainability.

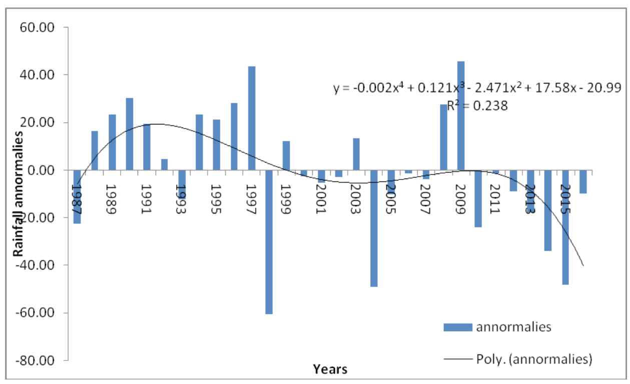

Figure 8. The anomalies of mean annual rainfall over Imo State (1987-2016)

5. Conclusion

Sustainable agriculture is very important to preserve life and growth of the economy of a nation. Therefore, government at all level should set up adaptive measure in guaranteeing that there is increase in agricultural production in the county as it is clear that Imo state experiences

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climate variability which could adversely impact on agricultural activities and consequently affect food supply, as this is a global phenomenon that is also influencing other nations of the world. However, the study observed that there has been annual fluctuation in temperature and rainfall, increase in temperature trend and decrease in rainfall trend across the years of study and in the last three decades studied, there are visible changes and variability in the pattern of temperature and rainfall in the state. The evidence seen on steady increase in surface temperature and decrease in rainfall is not favorable for agriculture especially in the state where agriculture is majorly dependent on rain-fed as its major source of water, this calls for serious concern. Therefore alternative sources of water supply and mechanized agricultural practice such as irrigation farming, drilling of bole hole in farm sites should be introduced in the state and weather reports should be published seasonally to support the agricultural sector in planning to reducing the risk of food shortage and policies on climate and sustainable agriculture should be implemented in the state.

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REVIEW

Rice and Climate Change: It's Significance towards Achieving Food Security in Nigeria: A Review

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ABSTRACT

Climate change is already impacting on every aspect of man life on earth especially in the agricultural sectors of developing nations. In Nigeria, and indeed the world over, seasons are shifting, temperatures are rising, landscapes are changing and sea levels are rising. Extreme weather events like drought and flood are becoming more frequent and pronounced.[3] stressed on the fact that Agriculture will suffer from major damage caused by changes in climate especially in the African continent. Nigeria is one of the African country that is highly vulnerable to the adverse effects of climate change, as Nigeria is still practicing rain fed agriculture [16]. The impact of climate change is experienced in form of extreme climatic events like flooding, severe heats, and droughts which has led to the degradation of soil and consequently low yield in crops. This will have consequences for rice cultivation in Nigeria, where the dominating climatic factor relied on by farmers in the choice of when to prepare the land for planting, the actual planting, the types of crop variety to plant and harvesting of crop is rainfall [23, 24]. The implication of this will be interference with food security as rice is an essential food crop in Nigeria that is consumed by a large number of the population. [26] has warned that hunger in Africa will be worsen by adverse effects of climate change, as it threatens the capacity of vulnerable countries like Nigeria to guarantee food security, eradicate poverty and actualize sustainable development in agriculture. The increasing rate of inadequacy in food supply in the world leading to different form of malnutrition is worrisome and more needs to be done in the areas of agriculture so as to guarantee food security to some extent and improve on nourishment, if a world without hunger is to be achieved by 2030.

1. Introduction

All over the world, adverse effects of climate change have become a national concern particularly in the agricultural sector [1]. This concern is due to the fact that climate change is creating unfavorable challenges in advancement of agriculture, food security and the general wellbeing of man [2]. [3] asserted that agriculture will significantly be

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affected by damage caused by changes in climate. Rice farming, particularly those dependent on rainfed, need certain acceptable climatic parameters to produce optimally and therefore are in danger due to climate change [4] especially if it comes with unfavorable conditions [1]. In Nigeria, production of crops and its yield is largely determined by variation in climatic factors mainly rainfall and temperature [5-9].

Several studies have attributed the setback majorly encountered in rice production to climate change impacts; [10-14] along with others factors. Evidence from these studies shows that variability in climate poses a danger to food security. It has been noticed that inconsistency in weather elements can lead to reduction in yield of crop and destruction especially at the onset of germination; hence to attain sufficiency in rice production in Nigeria, urgent steps must be taken to address the vagaries of these climatic elements. In Nigeria, the sector of agriculture is very important to its economy as it is the key engine that helps to stimulates growth and development. The agricultural sector still maintain a major position in the economy of Nigeria, as it contribute about 40% of the GDP and in the employment of about 70% of its youthful population that reside majorly in the rural area despite the revenue from the oil sector. Therefore, the changes presently experienced in climatic elements could pose a danger to the sustainability of agriculture if not checked [15, 16] resulting to food scarcity and unemployment especially bearing in mind the rapid growing population. Presently in Nigeria, rice is a major food consumed in most homes and a major source of calories for families, unfortunately this demand has not been sustained by local production hence the dependence on foreign rice to compensate for the shortfall in local production to prevent rice shortage.

Rice is consumed in large quantity by both the rich and the poor. [17] noticed that 70% of the entire populace of Nigeria feed on rice. In 2012, towards the end of the year it was observed that the total foreign debt and importation figures of rice added up to around one trillion of naira, causing importation of rice to have the highest figure of over 60% out of all import figures. But with the recent pronouncement and enforcement of the federal government, on the ban of imported rice more effort needs to be put in place to improve on local production to meet the large demand of rice in the country. Therefore, in order to avert food crises in Nigeria, which will be further complicated by an adverse climate condition necessary steps needs to be taken to improve on food crop production especially rice crop which is linked to food security of developing nation.

2. Effect of Changing Climate on Rice Production

Changes in climate resulting to increasing temperature can have a direct or indirect effect on rice farming, by influencing the capacity for its abundance or a dearth in its availability due to variability in pattern. The most important indicators in climate are temperature and rainfall, which is due to the role they play as both factors of climate as well as elements of climate as any changes in them have the ability to cause a change in the other element [1]. A prolong increase in temperature that exceed the required threshold for growth will have impact on rice production. This impact can cause growing season to be reduced, hence maximal yield will not be attained and consequently there will be shortage in rice production to meet the ever increasing demand.

Climate has a direct impact on the physical development of all stages of rice formation and growth. Changes in climate could also affect yield as well as growth of rice as a result of temperature and carbon dioxide. Rice plant is also affected indirectly by climate change through the occurrences of crop pests and diseases which prevent grain yields. The climatic environment in which rice grows is very important for attaining food security all over the world. Additionally, other activities that could influence rice yield are availability of irrigation water, competition with animals, changes in the fertility of soil and erosion. Changes in climate is creating an increased demand on the food supply structure of the world. Climate change is anticipated to cause an increase of food grain yield in some areas at higher latitude and cause a decline in yield at lower latitude [18]. The production of rice is faced with a lot of challenges resulting from global warming which has led to shortage of water and brought about other factor that incapacitate the ability of farmers to grow rice crop optimally. (e.g., [19-21])

Figure 1. Rice crop requires water at every stage of development

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It is imperative to note that, even with improvement in seedling, and the use of irrigation support system, agriculture in Nigeria is still highly dependent on weather and climate for production and sustainability of food crops. [22] In a tropical environment like Nigeria, where rain-fed agriculture is practiced majorly, the start and end of raining season determine the culture adopted by farmers. This is because most farmers await the first rain of the year before preparing land for planting ,selection of crop types, and time of harvest [23-24].

However, high rainfall and temperature with extreme weather conditions such as drought, flooding can affect and /prevent crops from growing, reduce crop production [15] and in other instances destroy crops. In Nigeria, in almost all the rice producing state flooding resulting from excessive rainfall is a major extreme climatic event that destroys rice farms leading to destruction of several hectares of rice farms and lose of billon of naira yearly. Evidences of such climate related extreme events is shown in Figures 2-6.

Figure 2. 280 hectares of Rice farm destroyed by flood in Iguomo in Ovia North-East of Edo state in 2018

Figure 3. 1000 hectares of rice farm destroyed by flood in Katsina State in 2018

Figure 4. 200 hectares of rice farm destroyed by flood in Anambra state in 2018

Figure 5. 5,000 hectares of rice farm destroyed by flood in Kano State in 2018

Figure 6. 4,000 hectares of rice farm submerged by flood in Maiduguri in 2018

Climate change threatens the capability of many nations, especially in Africa to guarantee global food security, poverty elimination and actualize sustainable development. Food security is a situation where all human beings, consistently have access to a reasonable amount of affordable, healthy food that is able to meets their dietary needs and the type of food they prefer for a functioning and healthy life [25]. [26] has warned that hunger in Africa is made worse by the effect created on agriculture by climate change. For example, the occurrence of drought is now a common happening in some part of the world,

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and in some cases persist for a longer time than usual. In Africa, some countries have suffer the worst kind of drought in the last decade notable among these countries are Rwanda, Kenya, Somalia, Ethiopia amongst other. [27] stated that over 70 million humans around the world are faced with hunger due to drought which is a consequent of climate change. Over the years a consistent shift in the climatic and weather conditions in Nigeria and specifically in northern Nigeria has become evident. This could be as a result of the general variability in the global climatic conditions due to global warming. For example, the onset of the rainy season on the average is normally expected to start in Northern Nigeria between late March and April, but the recent weather condition shows a deviation from this trend. As a consequent of this changes in the climatic condition of Northern Nigeria some part are now faced with drought. (Figure 7&8) this particularly has consequences for the Nigeria nation as the geographical northern region of the country is where majority of food crops are grown.

Figure 7. Drought affected rice farm in Northern Nigeria

Figure 8. Rice farm affected by drought

Therefore, the susceptibility of rice crop to global warming has become of key concern with current reality of its importance to the society and the attainment of food security.

3. Climate Change Effect on Wetland Used for Rice Cultivation

All over the world, wetland performs a very important task in the cultivation of rice crop for mankind either for consumption or as source of livelihood. The commonest agro ecosystems wetlands are those used for rice farming. These wetlands are very beneficial to mankind, as they provide habitation to a large range of biodiversity such as fish, insect and amphibians. Wetlands also play a crucial role in conserving the population of water birds [28]. In Asia, several rice farmers also keep fish in their rice farm as an alternative source of income.

In Tanzania for example, rice farming as well as cattle grazing is done widely on wetlands: these wetlands also account for up to 98% of household food that is consumed [29-30]. While the threat to wetland caused by agriculture is recognized, it is also imperative in recognizing the significant of wetlands for agricultural purposes for the cultivation of crops like rice and the rearing of livestock and also fishing in developing countries of the world [30-31].

Wetlands contribute significantly to countries with higher income, for instance, in prairies of Canada, wetlands have been intensely turned to agricultural lands by many farmers for the cultivation of crop [32].

In Nigeria, wetland contributes very significantly to agriculture especially in rice cultivation. This is as a result of the limitation of upland production systems to provide sustainable food security to their population. [33] Studies have shown that the major determinant of the structure as well as the functioning of wetland ecosystem is the degree of change in temperature and the quantity of water available from precipitation. Water is an important driver of wetland ecosystem functions, including the yield from crop, as well as other services that is helpful in supporting mankind. It serves also as the most important source in boosting production of food crops. Although artificial source of water supply is a good method of meeting the gap in water shortage to improve crop yield in most nations of the world, its usage and practice in Nigeria is low compare to other nations. Rainfed agriculture remains the main practice for rice farming and other crop. This is as a result of the dominant method of subsistence agriculture in most parts of Nigeria. Crop output from rainfed farming is still low as a consequence of reduced soil nutrients, high incidence of pests and diseases which is made worse by climate change over time and also the period of minimal or no precipitation at critical stages of growing when it is mostly needed. Water availability is key to gaining food productivity in wetlands as the functioning of wetlands is affected by changes in both temperature and rainfall. This is because, decomposition in wetlands are closely tied to variation in temperature and rainfall [34].

Wetland could become susceptible to climate change as a result of increased potential evapotranspiration due to increased temperature [35]. Consequently, these changes in climate variables will have impact on how wetland function and reduced the benefit derived from their usage by mankind for survival especially in the production of food crop like rice. Some ecosystems are more sensitive to climate change compared to others, but in most cases, their ability to withstand this climatic disturbances could be over stretch, which can led to irreversible losses and thereby affect the services its provide to mankind hence, the need to be proactive and provide adequate measures for mitigation should this happen. Changes in water quality and quantity can destroy the physical, chemical as well as biological properties of wetland [36-40]. Due to these changes, there will be shortage of water supply to the rivers, deficiency in groundwater, polluted water and sedimentation, brackish and salt water encroachment depletion of soil nutrient from soil erosion [41-42]. Since agriculture depend majorly on the hydrologic cycle, cultivation of food crops will be affected significantly by changes in rainfall, soil moisture content and evapotranspiration. Locally, the cultivation of agricultural food crops such as rice is likely to either increase or reduce depending on the climatic condition prevailing in the locality and other human factors. Wetlands in the tropics like Nigeria, depends directly on precipitation hence are likely to be influenced by climate change [43]. Therefore, with a hotter and drier climate, there could be a reduction in wetland size or a complete loss. It is necessary therefore, to build resilience to climate change as well as other disturbances when planning for any agricultural year so as not to miss the goal of achieving food security [44]. It is imperative that these factors are considered in early planning as change in wetlands affects those who depend on them for livelihood, especially the underprivileged that do not have any other means of survival [45].

4. Rice and Climate Change: Implication Food Security

Rice being a very important food grain is used to assess the level of food security in an increasing population of the world and Nigeria is one of these growing population .In Nigeria, rice is consumed by a large number of the population as scarcity and changes in its price is felt in many homes as has been witnessed in recent times. It has acquired a staple food status as many now depend on it for their calories intake [46]. All over the world, rice is among the commonest food crop for mankind, as they feed on it than other crops [47]. Presently in Nigeria, different varieties of rice are grown; some are indigenous while others have been introduced into the country. Nigeria has a land area of 923,768 million square kilometres with a total of 71.2 million hectares of farmable land, an estimated 4.6 million hectares is useful for rice cultivation but only about 1.8 million hectares or 39% is presently used for rice cultivation [48]. On the Africa continent, Nigeria is the first in rank in the consumption of rice which is due to its large population, largest producer of rice and also the highest in the importation of rice after the Philippines (Figure 9) which is largely due to the importance of rice consumption in the country. The food condition in Nigeria is particularly worrisome as has been seen of recent with a major rise in the price of rice causing untold hardship on the populace. Nigerian farmers generate more income from rice farming than other cash crops. Currently Nigeria is the highest in the production of rice in West Africa, as it produces an average of 3.2 million tons of paddy (2 million tons of milled rice) [49]. Rice imported into Nigeria was close to 3 million metric tons in 2008 alone, including 800,000 estimated metric tons that is alleged to have come into the country through illegal route yearly. irrespective of the crude oil boom, agriculture still maintain a strong base in the economy of Nigeria, as its provide income for many Nigerians especially those in rural areas.

Figure 9. A local rice mill in Nigeria

The agricultural sector faces many challenges, ranging from the use of obsolete land tenure methods that deprive farmer from having access to adequate land (1.8 ha/farming household), less use of artificial source of water supply to make up for shortfall in rainfall, non implementation of research recommendation and obsolete machinery,

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increase in cost of farm input due to high exchange rate of the Naira to other currency, lack of access to loans, ineffective method adopted in the purchase and distribution of fertilizers to farmers, non availability of adequate storage facilities for farm products and access to good rood network connecting farm land to market which has contributed also to the low productivity in agricultural products (average of 1.2 metric tons of cereals/ha) combine with waste and losses suffered after harvest.

Rice produced in Nigeria comes from the middle belts area, States in southeast and also northern part of the country [50]. Rice is an important food crop that is consumed globally; although it has the capacity to adjust to different climatic condition, but its ability to withstand extreme climatic events will depend on the degree of severity of such events. About 90% of the world's rice is propagated in tropical, semitropical regions and eaten where they are produced by farmers who work on small scale especially in countries with low income [51]. Rain-fed lowland rice is the most prevalent rice system practiced in Nigeria, with a sum of over 50% of the entire rice –developing regions in Nigeria; about 30% of rice produced comes from rain fed upland rice, and just about 16% comes from irrigation farming that is high in yield [52]. In around 25 million hectares of land utilized for development in 2000, for a few food crops classifications, just a little extent of 6.37% was utilized for rice development. Within this period, the yield from national rice produced went up to an average of 1.47 tons for each hectare of land.

An appreciable advancement was made in 1990 with respect to the quantity of rice produced where output from rice production appreciated to 2 million tonnes on the areas where there was cultivation of rice as yield also increased to 550 thousand hectares and 1.98 tonnes for each hectares respectively [53].

The primary aim of food security is to focus on the ability of every human being to have access to food that is needed for nourishment and matters that relate to how agricultural policies are formulated, economic wellbeing and trade [54]. Developing nations of the world like Nigeria are most often faced with malnourishment which is most times associated with not having access to quality food and the inability to effectively distribute available food. That food is available in a country does not necessarily mean that every one that needs it has enough of it. Food security at the level of the individual is when a person either have adequate income to purchase food or they have ability to produce their own food through subsistence cultivation. Food security exists when all individuals consistently have physical and economic admittance to protected and nutritious food which meets their dietary necessities and food inclinations for a functioning and solid life" [25].

As indicated by [55], food security is based on three pillars which are

(1) Food accessibility: adequate amounts of food accessible on a reliable basis.

(2) Food access: The ability to acquire enough resources to get the necessary food for a healthy nourishment

(3) Food uses: proper use of food available based on our understanding of basic nourishment and care, in addition to sufficient water and good hygiene

Other effects of climate change on agriculture is that it has the potential to interfere with the economic progress of a nation thereby causing extreme hunger of the populace particularly changes that comes with unfavorable impacts.

5. Relationship between Climate Change and Hunger

Climate change has impact on all areas of the food system (i.e) productivity, availability, quality as well as food system stability. This impact is felt more in countries with high levels of hunger that are also highly vulnerable

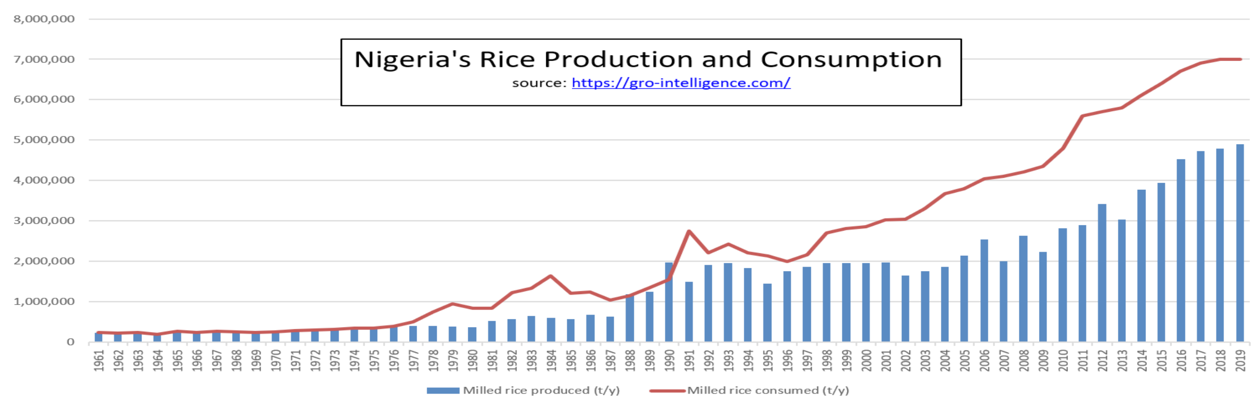

Figure 10. Nigeria's rice production and consumption from 1961 to 2019

to adverse effects of climate change because they lack the ability to adapt. Climate change poses a danger to the high increase in the number of hungry and malnourished people. Climate models have predicted higher average temperature in most region of land and oceans, hotter extremes in many regions, excessive precipitation and the likely occurrences of drought in some regions which have all created extra threat in reducing hunger. In Nigeria, and indeed the world over, seasons are shifting, temperatures are rising, landscapes are changing and sea levels are rising. Extreme event like drought and flood are becoming more frequent and pronounced. Among the consequences of a changing climate is their impact on agriculture which has lead to the issues of food scarcity resulting to hunger and consequently a volatile population especially with a nation like Nigeria with a very active youth population that is increasing rapidly. In Nigeria, the population has been projected to increase by well over 50 percent in the next two decades [56]. Within these 20 years, the population of the rural areas is projected to grow by over 25%, while the growth projected for the agricultural sector is expected to increase at a slightly lesser percentage, this is further modify by climate change and inadequate financing of the small scale farmers who form the bulk of farmers. [57] stated that African countries will suffer the greatest threat occasioned by climate change to agriculture where agricultural yield and production of food per person has been on the decrease and growth of population will increase the need for more food and water in the next 30 years to come. Globally, more than 850 million people do not have adequate food [58]. This condition is most likely going to be worsen in future as a consequent of climate change, as instability in food supply in many country including Nigeria will rise with just about 2^{o}C increase in temperature (applicable to the 1990 basic standard).With a further increase in global warming of between 2-4^{o}C, universally, agriculture is projected to decline in productivity in the tropics with more destructive effects as crops are most times near their best in the region [59]. Changes in climate are already causing disruption in the production of major food crops like wheat, rice and maize in tropics and temperate regions and if climate resilience is not built, this condition will be worsen in the coming decades as temperature continue to rise and becomes severe. WHO study in 2018 shows that the number of unhealthy people have the tendency to be greater in countries where exposure to climate change is most severe. Malnutrition is also greater in these countries where exposure to extreme of climate change is high. This condition is also complicated when such population depends largely on agricultural methods that are highly susceptible to climate change. Temperature anomalies over agricultural lands used for farming has continued to be greater than the long term average throughout 2011-2016, bringing about more persistent spells of severe heat in the last five years. Rainfall pattern and duration is changing, giving rise to early start of raining season or late start and the irregular distribution of rainfall seasons which is a major requirement for farming in Nigeria. The harm from climate variability to agricultural productivity is contributing to the shortage experienced in food crops, and indirectly causing hikes in prices of food crops and losses in income that reduces people ability to get the required food for survival and resulting to food scarcity and consequently famine and undernourishment.

6. Conclusion

Climate change impacts have been linked to food insecurity, malnourishment and hunger. Climate change and its variability affect rainfall occurrences and distribution and consequently changes in agricultural Seasons. The key factor giving rise to hunger and undernourishment in developing countries is the severity of climate change happening in these countries resulting to frequent flooding and droughts. The increasing rate of food scarcity in the world leading to different form of malnutrition is worrisome and more needs to be done in the areas of agriculture to ensure food security and improve on nourishment if a world without hunger is to be achieved by 2030. Therefore, all hands must be on deck to hasten and strengthen the capacity of vulnerable nations like Nigeria to respond swiftly to climate change issues and extremes.

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ARTICLE

Implication of Household's Income Composition on Infrastructure Maintenance in Residential Core of Akure, Nigeria

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ABSTRACT

This study examines the implication of household income composition on infrastructure maintenance in the residential core of Akure, Nigeria with a view to providing suggestive recommendations that will remedy identified problems in the research locale. With regards to this, an estimated of 1% research population, amounting to 425, were served with questionnaires using systematic random sampling technique with replacement. Findings revealed that residents in the study area are low income earners with larger population influenced by market proximity, low prices of staple food items and affordable but tumbledown housing. Likewise, essential facilities are in poor state owing to poor maintenance. Besides, household income induced variables considered in the study, which accounted for 75.6% of the challenges limiting routine facilities maintenance in the study area. The study recommends skill acquisition training, resource collaborative efforts and soft loans scheme to boost the income generation of residents in this locale.

1. Introduction

Household income, in economic parlance, is contextually envisaged as receipts, proceeds or revenue that are received or generated by the household or individual members of the household at annual or more frequent intervals [1]. Household income, without any iota of doubt, is a handy empirical tool for investigating human wellbeing in his abode and material prosperity in a contemporary society. This is obvious in his housing stock, environmental vista and infrastructural facilities in his domain. It is pertinent to note from time immemorial till date that man in his quest to assume better income standing among his contemporaries is on a passionate search for employment opportunities, education, and technological innovations among others. This resultant adventure had retrofitted into human membrane a stimulus for rural-urban drift as well as movement across transnational boundaries with a view to achieving goals and aspirations of economic prosperity. This has invariably brought to being rapid urbanization characterized with population explosion in our towns and cities with attendant physical planning implications.

The fact remained that urbanization on the positive flip heralds an environment that is heterogeneously composed and exponentially convoluted. This accelerates the coming together of urban populace of different tribes, religion and

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socio-economic posture with a common front of developmental activities in our towns and cities. This is even viewed from the perspective that cities are epicenter of economic density and productivity; thus, enhancing the positive benefits of firms locating in close proximity to one another [2]. In spite of this gains associated with urbanization in the developed world, the reverse is the trend in Nigeria and Africa in general with grave consequences occasioned by poor urban governance. Issues of urban structural transformation are not taken with seriousness by government at all levels; thus, culminating into inadequate job creation, poor infrastructural facilities, housing challenges, and access to basic services [2]. The effect of this mismatch between urban population and infrastructural facilities is devastating leaving urban infrastructure overstrained and in deteriorating condition calling for prompt maintenance attention.

Ogunbajo, *et al* [3] were quite categorical on this subject-matter when they averred that the carrying capacity of infrastructure systems to stimulate socio-economic development solely lies on its maintenance management. Conversely, infrastructural facilities are most often left unattended to, until it attained the state of deterioration in Nigeria [4]. This is unhealthy and an albatross to per capita development and poverty alleviation. It is pathetic to note that institutions of government responsible for infrastructure management in Nigeria had failed in this direction owing to dearth of funds and other systemic encumbrances.

In a bid to arrest this ugly development in her infrastructure sector, the federal government in 2005 enacted Infrastructure Concession Regulatory Commission Act (ICRCA) [5]. This was designed to allow for private sector inclusion in infrastructure management and thus conceded some of her critical infrastructure which include telecommunication, railway projects, electricity, and waste management, among others. While this strategy has yielded positive results in the telecommunication sector [4], no meaningful achievements had been recorded in other infrastructure sectors. This unfortunate turn of circumstances had constrained households and neighbourhood; especially, in the urban setting to seek self-helps in making infrastructural facilities in their locale functional.

In the words of Yoade [6], income is the primary determinant factor influencing household's decision on what part of the city to reside. Similarly, the level of infrastructure maintenance provided in any place of abode is a product of income. It is, therefore, from this insight that this paper tends to examine the implication of household's income on infrastructure maintenance in the Akure city core.

2. Literature Appraisal

Urbanization trend is a global phenomenon. The developed climes across the planet earth such as Europe, America, and the Caribbean are urbanized continents with about 75% of their population living in cities [7]. The fact remained that urbanization in developed nations has engendered high level of positivism in their developmental process. This is characterized by spatial distribution of human and material resources paving way for efficiencies in infrastructural facilities and services in these climes [2]. This, in no small measure, emplaces prosperity, higher education, lower fertility, and higher life expectancy in these developed regions of the world. Urban centres in these developed countries are product of spatial planning and not as a result of spontaneous development.

In an exclamatory remark on the trajectory of urbanization in Africa, UN-Habitat [8] pointed out that Africa is in a period of historic change in her demography. This astronomical increase in population in African countries is not at par with infrastructure requirements of her fast growing urban centres [9]. This lack of adequate and efficient infrastructure systems; especially, in Sub-Saharan Africa constitute a major impediment to socio-economic development as it stifles economic growth and inhibitor to poverty reduction across the region [8]. This could be attributed to the reason why poverty is on the increase in developing countries; especially, Africa where overwhelming majority of her population in the low income group are lacking the basic necessities of life [10].

It is no longer news that Nigeria is in dearth need of infrastructure to grow her economy. In the estimation of the National Planning Commission [11], about three trillion US Dollar will need to be invested over the next 30 years to provide and maintain adequate infrastructure in Nigeria. This remained a daunting task looking at the fact that oil prices in the international market is on the downtrend, occasioned by Covid-19 pandemic that put the country's economy at greater risk of recession for the second time over the space of four years after the 2016 economic meltdown. This calls for diversification from the monopolistic oil sector economy to agriculture, manufacturing and service industries which could only be achieved through investment in infrastructure.

Looking at the economic realities on ground and poor utilization of resources coupled with corruption during the period of oil boom in Nigeria, every tier of her government is incapacitated in their obligations of providing and maintaining urban infrastructure [12]. It is even sardonic to point out that infrastructure projects under concession such as electricity is in pitiable state with overwhelming majority of her population being subjected to frequent power outage. The bottom line of this discourse is a pointer to the fact that a nation cannot be rich without quantum of adequate and functional infrastructure [5]. Thus, a once prosperous oil rich nation, as Nigeria, is now being infamously regarded as nucleus of poverty in the world.

This shackle of poverty had resulted into residents living in overcrowded dwellings with nonexistent or acute shortage of household and neighbourhood facilities typified by slum development as well as socio-spatial disorderliness [13-14]. This is even compounded by scarcity of white collar jobs and poor enabling environment for the informal sector economy to generate blue collar jobs for the teeming urban migrants. A study conducted by Brook and Smith [15] revealed that majority of Lagos residents live in shared apartment blocks with an average of seven persons. This set of occupants share the same latrine and small bathroom which is often located outside the buildings [16]. Taking into cognizance the rate of abject poverty in Nigeria, Bankole and Oke [17] was of the opinion that majority of her residents live in unhealthy and filthy environment based on their income levels.

The challenge of urban poverty characterized by poor infrastructure provision and maintenance is more precarious in the core of Nigerian towns and cities. These areas are not well laid out; hence, they are overcrowded and occupied by people of low per capita base. Houses in these environs are built without reference to acceptable planning standards. They are marked by high level of filth, crowding index and epidemics susceptibility [18-19]. Owoeye [20] argued that inhabitants of these old traditional residential districts are shrilly incapacitated by financial wherewithal in the routine maintenance of infrastructural facilities in their domain. Although, the blame of infrastructure decadence in these residential cores should not be apportioned on the inhabitants alone but also on government for neglect, policy summersault and social isolation of people in area of infrastructure management [21].

Generally speaking, higher income induces economic development which in turn manifest in decent housing and better infrastructural facilities [22]. According to them, the latter is a composite means for generating the former. This is mirrored from the point that stable power supply reduces the cost of production as well as creates an enabling environment for small and medium enterprises to thrive thereby creating jobs for the teeming unemployed urbanites. Good transportation and effective communication networks on the other hand saves travel time, reduces travel cost and, ultimately, facilitates trading activities which on the long run increases per capita development. It is from this viewpoint that this study sees infrastructure as dynamo for raising income and tool for addressing revenue inequality. Thus, its development provides an array of influential strategies for tackling urban poverty, which this study intends to investigate as far as the residential core of Akure is concern.

3. Research Methodology

3.1 Overview of the Study Area

Akure is a fast evolving city in the southwest geopolitical landscape of Nigeria. It is a home to number of tertiary institutions and commercial centres. Chief among these include the Federal University of Technology, Federal College of Agriculture, International Auto-mart Station, among others. Spatially, the city is located within latitude $7^0 15^1$ and $7^0 28^1$ north of the equator and longitudes $5^0 6^1$ and $5^0 25^1$ east of the Greenwich meridian [23]. The city is situated within the tropical rainforest of Nigeria where rainfall and humidity is high throughout the year. It is the administrative seat of Ondo State which came into being in 1976. The population of the city has witnessed incredible exponential increase, swelling from 353,311 in 2006 to an approximate 589,376 in 2020 based on a projection of 3.2% growth rate per year. The spatial extent of this research is limited to Akure residential core, as clearly defined in Figure 3. The choice for this part of the city was informed by high level of decrepit infrastructure occasioned by poor maintenance, low per capita development, resident's negligence and ineptitude [20, 24]. Seven out of the twenty-two neighbourhood in this part of the city were systematically chosen for this study going by their proximate arrangement and magnitude of infrastructural decadence. These include Imuagun, Odo-Ijoka, Araromi, Oja-Oshodi, Odo-Ikoyi, Isolo, and Obanla. Figures 1-3 showcase detail description of the study area from national to local context.

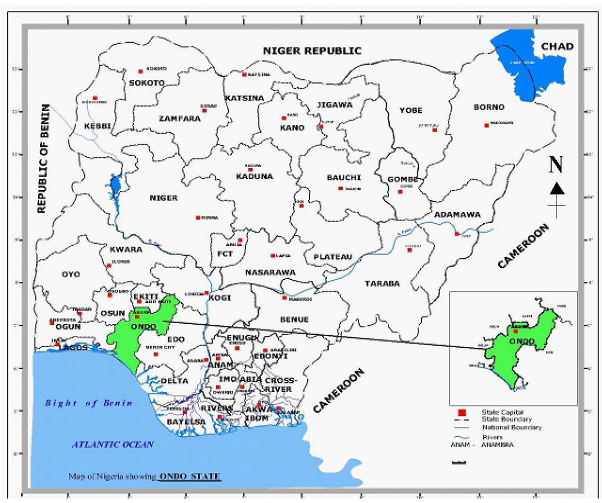

Figure 1. Ondo state in the national setting

Source: Ondo State Ministry of Physical Planning and Urban Development (2019).

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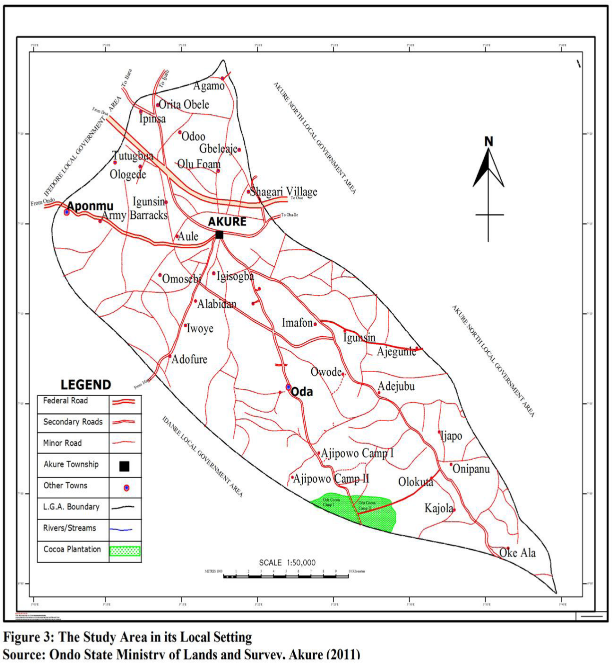

Figure 2. Akure and its major settlements in the local govt. setting

Source: Ondo State Ministry of Physical Planning and Urban Development (2019).

3.2 Research Database

It is imperative to note that the population of the study area was unknown going by the fact that population censuses conducted from time immemorial in Nigeria were not disaggregated into neighborhoods. Thus, with a view to collect data scientifically from the research locale, building population survey was carried out using Google Earth and ArcGIS to arrive at 1696 buildings. The average household size in Akure city, according Ondo State Bureau of Statistics [25], was put at five persons per family (5ppf) and five households per building (5hpb). Therefore, the estimated population of the research locale for 2019 was computed at 42,400 persons. Thus, a 1% of this estimated research population was chosen for questionnaire administration which is considered reasonable taking into consideration similar infrastructure maintenance challenges confronting residents in this locale as well as having homogenous socio-economic characteristics in an unvarying physical environment. These structured questionnaires were administered using systematic random sampling technique with replacement at the interval of twenty buildings. Retrieved questionnaires were analyzed and interpreted using appropriate statistical tests.

4. Result and Discussion of Findings

The subjects of discourse to be analyzed and interpreted in this paper are income distribution of respondents, factors influencing residents to living at the core of Akure, condition of infrastructure in the study locale, relationship between household's income induced variables and level of infrastructure maintenance as well as implication of these variables on infrastructure maintenance.

4.1 Income Distribution of Respondents

Data retrieved from respondents in the residential core of Akure city, as elicited in Figure 4, revealed that 21.6%, 24.9% and 30.1% of residents in this locale received average monthly gross household income of between ₦20000 - ₦30000, ₦30000 - ₦40000 and ₦40000 - ₦50000 respectively. By the virtue of the Nigerian new minimum wage act of 2019 which was pegged at ₦30000 and the submission of ODSBS [24] that an average household in Akure urban is five persons, it could be argued that resi-

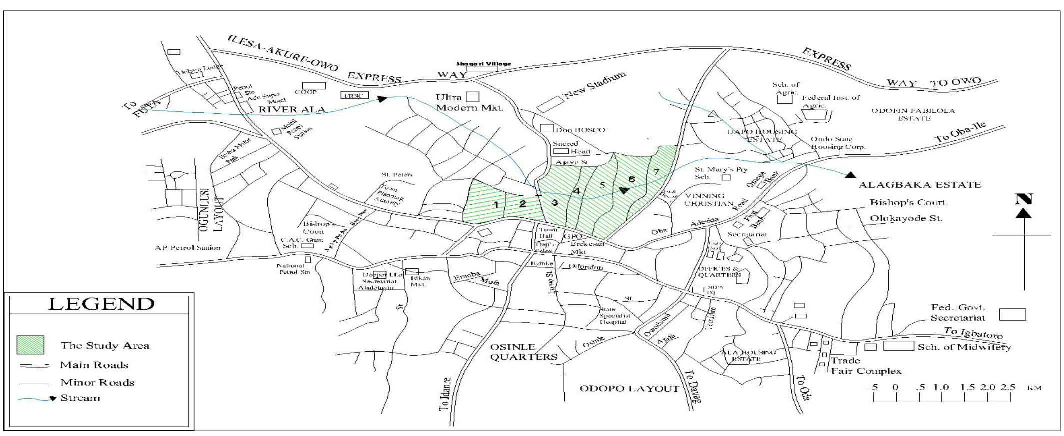

Figure 3. Akure Street map showing the research location within the residential core of the city

Source: Olasemojo & Owoeye [21].

dents in this study locale were low income earners living below the poverty line.

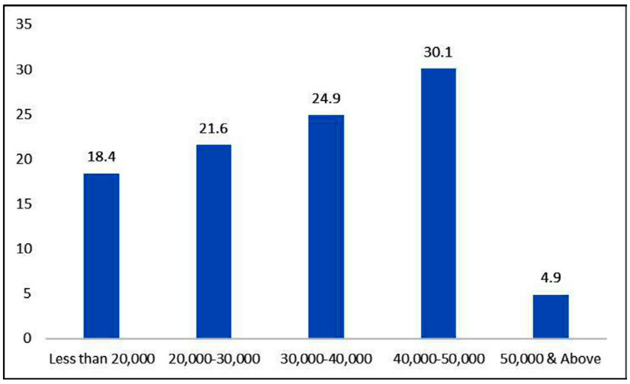

Figure 4. Percentage household income distribution of respondents in Naira (₦)

Source: Field Survey (2019)

This finding was in total agreement with the view of Rotowa *et al.,* [24] that the core of Akure residential neighborhoods was predominated by low income earners. It is in the light of the foregoing that Akinbamijo [19] counseled that any meaningful intervention designed to mitigate urban deprivation must address issues of substantial increment in income generation on the part of the marginalized urbanites.

4.2 Factors Influencing Residents to leave in the Study Area

The variables designed to explore the catalytic factors influencing households to this part of Akure city were designed on a rating scale of five options, where: Strongly Agreed (SA) = 5, Agreed (A) = 4, Undecided (UND) = 3, Disagree (D) = 2, and Strongly Disagree (SD) = 1. These set of options thus served as the basis for establishing agreement, indecision and disagreement with respect to the subject-view. In the course of this survey, it was revealed that housing in this locale was relatively affordable and cheaper when compared with the transition and peripheral zones of Akure city. As such, the poor urban households and rural migrants tend to settle in this area owing to their low income status. This was empirically proven in Table 1 with a mean mark of 4.03. Despite the fact that housing was relatively affordable; the issue of habitability was nothing to write home about. This statistical revelation was in tandem with the study of Owoeye [20] on environmental habitability in this locale where he established that the problem of livable dwellings with minimum acceptable standards persists in the core of Nigerian towns and cities, with proven evidences in Akure residential cores.

Table 1. Factors influencing households to Akure residential core

Factors	Means	Std.
Cheap housing	4.03	1.416
Proximity to market	4.13	1.387
Cost of living	4.23	1.281

Source: Field Survey (2019)

Proximity to market was found in the course of this research to be one of the principal factors influencing household's decision to settle in the core of Akure city. This was evident in Table 1 with a mean score of 4.13. Clusters of markets, which include Akure Central Market, Isolo, Erekesan, and Adedeji markets among others in this locale availed these low income urbanites to make a living through petty trading, artisanal enterprises and menial jobs like truck-pushing, hawking, vending and so on. Akinbamijo [19] led credence to this finding when he empathized that these group of people live from day to day rather than working to secure a future. Similarly, data extrapolated from respondents showed that low cost of living as elicited in Table 1 with a mean value of 4.23 was a motivating factor influencing low income households to reside in Akure core. Observations and on-site investigation revealed that prices of staple food like garri, beans, vegetables and varieties of grains were relatively cheaper when compared to the transition and peripheral zones of the city. Thus, these set of low income earners tends to settle in these environs with a view to maximizing the comparative advantage of market proximity to their place of abode.

4.3 Condition of Infrastructural Facilities in Akure Residential Core

The variable measuring this subject-matter was designed using a Likert scale of five options, where: Very Satisfied (VS) = 5; Satisfied (S) = 4; Fair (F) = 3; Dissatisfied (D) = 2; Very Dissatisfied (VD) = 1. It is not out of place to assume that road infrastructure provision and maintenance is not within the reach of average urban households because of huge financial resources involved. Thus, in most circumstances, the level of paved roads in towns and cities is a product of their government inter-

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ventions. With regards to Akure urban core, data obtained from respondents and observations in the course of this survey all pointed to a verity that road infrastructure in this area was fair. This was evident in Table 2 with a mean value of 3.03. This was an indication that Ondo State Agency for Road Maintenance and Construction (OSAMCO) and the Direct Labour Unit of Ministry of Works and Infrastructure were up and doing in their statutory mandate though with a lot of ground yet uncovered; especially, as it relates to rehabilitation and renovation of certain portions of roads in the city.

Table 2. Condition of infrastructural facilities in the study area

Condition of facilities	Mean	Std
Road	3.03	0.797
Electricity	2.23	1.060
Water	1.84	1.062
Waste management	3.19	1.180

Source: Field survey (2019)

Electricity facilities and power supply, going by the submissions of sampled respondents, was worrisome. This was elicited empirically in Table 2 with a low mean score of 2.23 pointing to dissatisfaction on the part of residents in the area. It is momentous to note that electricity is one of the infrastructure sectors that had been unbundled and conceded to private investors. It is quite heartrending to note that this engine of economic development is not relatively accessible to low income households of Akure residential core. The plight of these urban poor is marked with arbitrary metering with exorbitant monthly estimated bills which is not within the purse of this set of people leading to regular disconnection, power outage and, ultimately, poor maintenance of electrical installations in their domain.

As also shown in Table 2, water facilities in the core residential neighborhood of Akure is in pitiable condition with a low mean mark of 1.84. It is even pathetic to note that due to current economic realities, institutions of government in Nigeria are constrained in their primary mandate of pipe-borne water facilities provision and maintenance. This statistical discovery was in consonance with the assertion of Macheve, *et al.*, [26] where it was established that 99% of water supply system solutions were provided by households in Port-Harcourt. The resultant effect of this unwholesome development predisposes low income households residing in Akure residential core to the use of unhygienic water from unsafe sources which is pernicious to their health.

With regards to waste management, data retrieved from respondents showed that this element of discourse was reported to be fair with a mean score of 3.19. A cursory visit to this locale gave credibility to this statistical finding, which was contrary to existing literature on this subject-matter. Basically, the study identified low acuity of residents to waste disposal and non-functional of waste management authority in this locality as potent factors triggering apathetic behavior among the residents. It could be argued that this new development was informed by the concession of waste management activities to a private company called Zoon Lion Alliance Company with reasonable waste management bills which is not out of reach of low income households living in this locale. All the same, their functionality in term of regularity and effectiveness in collection is limited and very low compared with rate of waste generation.

4.4 Household Income Induced Variables and Level of Infrastructure Maintenance Nexus

Having established in Table 2 that electricity and potable water facilities were in deplorable state as a result of poor maintenance, it then became imperative to examine the link between household income induced variables and level of infrastructure maintenance. This is hinged on the fact that electricity and power supply is a private business administered by corporate organizations while potable water supply is more or less a household affair in Nigeria. Variables at play for household income induced elements, which serves as predictor variables are cost of maintenance and non-response to maintenance while the outcome variable is the level of infrastructure maintenance. These set of variables were designed on ordinal scale of measurement and, as such, were transformed using double-log transformation to assume approximate normality needed to carry out Pearson Product Moment correlation employed for this test. Results generated from this statistical test revealed that all the variables at play, with regards to the subject under investigation, were significant at $P < 0.01$. Going by the data in Table 3, it is crystal clear that there was strong positive relationship between cost of maintenance and level of infrastructural facilities maintenance with a correlation coefficient of 0.870. Likewise, there was strong positive relationship between non-response to maintenance and level of facilities maintenance.

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Table 3. Zero order correlation matrix

	(Y)	(X_1)	(X_2)
State of infrastructure maintenance (Y)	1.000		
Cost of maintenance (X_1)	0.870	1.000	
None response to maintenance (X_2)	0.872	0.771	1.000

Source: Computer print-out (2019)

The significance of these findings was not unconnected to the fact that cost and response to facilities maintenance are influenced by income. Unfortunately, residents of Akure core are low income earners, who could hardly cover household feeding expenses let alone infrastructural facilities maintenance. This is clearly represented in Figure 4.

4.5 Implication on Infrastructure Maintenance

It is evident in Table 4 that household income induced variables considered in this study, which are cost of maintenance and non-response to maintenance, revealed a correlation coefficient of (R) = 0.870 and coefficient of determination (R^2) = 0.756 with regards to level of facilities maintenance. This signifies that the model comprehensively accounted for 75.6% of the variance that could be explained with respect to household income induced variables and level of facilities maintenance in the core of Akure city.

Table 4. Regression model summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.870	0.756	0.755	0.18405

Note: Predictors: (Constant), cost of maintenance, none response to maintenance
Source: Computer print-out (2019)

The resultant state of poor facilities maintenance; particularly, in electricity and portable water facilities in Akure city core occasioned by resident's low income standing was obvious in their poor functionality, vandalism, theft, and premature deterioration. This has, in no small measure, subjected households in this locale to untold hardships ranging from small and medium enterprises development challenges to water-borne related epidemics susceptibility.

5. Conclusion and Policy Recommendations

In a nutshell, the binomial interplay between household's income and infrastructure management has been scrutinized in this study. The crux of this matter remained that these elements of discourse are indispensable. This is even viewed from the point that an improvement in infrastructure provision and maintenance will stimulate an increase in household per capita development and vice versa. It is pathetic to reveal in this study that households in this locale were low income earners who lack financial means to maintain infrastructural facilities in their domain. The predicament of these households was further worsened by government inability to fix critical facilities like electricity, waste management, water provision among others leaving her to no other choice than conceding them to corporate organizations. While substantial achievements are made in area of waste management, though not sufficient enough as revealed in this study; the functionality of electricity facilities, power supply and pipe-borne water was appallingly poor. The effect of this quandary on Akure core households is multifarious which include exorbitant electricity bills, power outage, vandalism, theft, and lack of potable water for household consumptions. It is in the light of this foregoing that the following recommendations are advocated:

(1) In spite of residents' low income status, collaborations between neighborhoods in the core of Akure to provide and fix existing faulty facilities like pipe-borne water and electricity by pooling resources together would go a long way in addressing these aforementioned maintenance challenges.

(2) Corporate organization responsible for electrical installations, repair and maintenance should be alive to their responsibilities by making power supply available to households in the study area with a view to stimulating the growth of small and medium enterprises, taking into grasp the comparative advantage of the area being an economic hub of Akure city.

(3) Likewise, issues of outrageous bills beyond the purse of poor residents should be discouraged to prevent unnecessary confrontations that could precipitate into vandalism of few available facilities in the area.

(4) Infrastructure Concession Regulatory Commission Act (ICRCA) of 2005 should be stringently enforced and regularly reviewed to meet current realities while corporate organizations in charge of critical infrastructure be put on their toes for efficient service delivery.

(5) As a matter of urgency, government institutions like Nigerian Directorate of Employment (NDE) should incorporate low income households in their skill acquisition programs while Ondo State Microcredit Agency (ODSMA) be ready to offer them soft loans for commercial purposes with a view to boosting their income generation.

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Conflict of interest

Authors declare no conflict of interest.

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ARTICLE

Evaluation of Sediment Yield Predicting Models of Ghana

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ABSTRACT

Fluvial sediment transport data is a very important data for effective water resource management. However, acquiring this data is expensive and tedious hence sediment yield modeling has become an alternative approach in estimating river sediment yields. In Ghana, several sediment yield predicting models have been developed to estimate the sediment yields of ungauged rivers including the Pra River Basin. In this paper, 10 months sediment yield data of the Pra River Basin was used to evaluate the existing sediment yield predicting models of Ghana. A regression analysis between predicted sediment yield data derived from the models and the observed suspended sediment yields of the Pra Basin was done to determine the extent of estimation of observed sediment yields. The prediction of suspended sediment yield was done for 4 out of 5 existing sediment yield predicting models in Ghana. There were variations in sediment yield between observed and predicted suspended sediments. All predicted sediment yields were lower than observed data except for equation 3 where the results were mixed. All models were found to be good estimators of fluvial sediments with the best model being equation 4. Sediment yield tends to increase with drainage basin area.

1. Introduction

Sediment yield (SY) of a basin refers to the total amount of sediments delivered from the catchment expressed as (t yr^{-1}) whilst the annual specific sediment yield (SSY) is obtained by dividing annual suspended sediment yield by catchment area (t km^{-2} $year^{-1}$) [1-4]. It is a useful measure of the sediment delivery ratio of the basin. Sediment yield from a catchment is a function of several anthropogenic and physical factors that influence erosion and sediment transport in the basin. The factors include farming, mining, construction, basin slope, basin area, geology and rainfall intensity and the natural drainage network [1]. The effects of these factors on sediment load vary in time and in space. In most cases, several of these factors may control sediment load of rivers in an area [5-7]. Fluvial sediment transport data is a very important data for effective water resource management [8]. However, acquiring fluvial sediment data in-situ is quite expensive and challenging [9-10], consequently sediment yield modeling has become an imperative alternative. Many authors in the past have used varied methodologies to estimate sediment yield of rivers that have no direct measured data [6, 11, 12, 13]. These sediment yield estimation methods among others

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are the erosion rate method, catchment-based method, rating curve method and regression method [6].

In Ghana there exist scanty sediment data on the country's water bodies [8]. Early sediment studies undertaken in the country were mainly of short duration and were associated with specific projects such as hydro-power, potable water supply, irrigation among others [14-18,12]. In the 1980s and 1990s, attempts were made to implement systematic collection of sediment data in Ghana by Water Research Institute of Ghana [12,19,20], but the initiative was unsustainable as the sampling programmes proved too expensive to maintain [12]. In recent times however, there have been academic studies on fluvial sediment transport in the country [21-25].

Sediment budgets typically require estimates of (1) basin-wide sediment yield, (2) erosion rates from upland, channel, and floodplain sources, and (3) changes to the volume and residence time of material in downslope storages [26-27]. Quantifying these variables is usually more practicable in small catchments [27-29] where direct measurements of erosion rates and storage terms can be made. However, budgets are difficult to construct in very large catchments because the delivery of eroded material from slopes and its storage in channels become more complex, and its measurements are subject to greater uncertainties, with increasing scale [27]. Therefore, quantifying these processes typically requires careful measurements within the framework of long-term monitoring programs [30-32, 26-27].

A complementary approach is the use of models to predict sediment budgets/sediment yields especially in wider river basins. This is because local or regional rivers often show similar characteristics; hence reliable estimates of sediment yields could be obtained from a regression equation that is derived from data on regional rivers that have broadly similar characteristics [6]. Catchment sediment yield modelling has become imperative because population growth causes increases in land use and land cover changes and coupled with threats of climate change, water resources will be threatened, and this will have dire consequences on economic activities and livelihoods in the country [33].

Based on factors that influence sediment yields and geographical conditions several sediment yield predictive models have been developed across the world to estimate fluvial sediment transport. A few examples [34-38] centred on annual specific sediment yield (SSY) are outlined in Table 1. Reference can be made to other models in the following literature [39-41] and many others. Though these models are convenient means of estimating sediment yields, they are however saddled with some degree of uncertainties and must be used with some caution especially in developing countries where such models were developed base on insignificant data.

Sediment yield predictive models for ungauged rivers have been developed for the southwestern river basins in Ghana [9], the Volta basin system [12], and the Pra River Basin [42] using runoff and catchment area as determinant factors. Boateng et al. 2012 [6] have also used only drainage catchment area as a parameter to estimate fluvial sediment input of Ghanaian rivers to the coastal sediment budget of Ghana. In this paper, 10 months sediment yield data of the Pra River Basin [2] is being used to evaluate the existing sediment yield predicting models of Ghana. A regression analysis between predicted data derived from the models and the observed suspended sediment yields of the Pra Basin was done to determine the degree of over/under estimation of sediment yields base on the co-efficient of determinations of the regression models.

Table 1. Examples of sediment yield predictive models

Model	Location	Reference
$SSY = 1.49 \times e^{1.24PGA} \times MLR^{0.66} \times e^{-0.05TreeCover} \times Ro^{0.24}$	Africa	Vanmaercke et al., 2014 [38]
$SSY = 0.86 \times S - 0.269 \times SWC + 10$	Ethiopia	Haregeweyn et al., (2008) [36]
$SSY = 114.54 + 1.567 \times A - 5.023 \times PER + 116.14 \times L_{em}$	Italy	Grauso et al., (2008) [35]
$\log SYY = -0.8838 + 0.8140 \log R - 0.3906 \log Q_{max}$	Colombia	Restrepo et al.,2006[37]
$SSY = 654 + 38.4\ LCs + 10.2P_{max} - 3787\ HI + 0.815\ EL_{ch} - 5711R_{pk}$	Asia	Ali and de Boer 2008 [34]

Note:
SSY: predicted annual specific suspended sediment yield (t km^{-2} y^{-1}); e: exponential fit; PGA: average expected Peak Ground Acceleration with an exceedance probability of 10% in 50 years; MLR: average height difference within a radius of 5 km; TreeCover: estimated percentage of the catchment covered by trees; Ro: estimated average annual runoff depth; S: slope gradient (%); SWC: areal coverage of soil and water conservation measures (%); A: catchment area (km^2); PER: catchment perimeter (km); L_{em}: erodibility index; R: mean annual runoff (mm yr^{-1}); Q_{max}:,maximum water discharge (m^3s^{-1}); LCs: % snow/ice cover; EL_{ch}: upstream channel elevation; HI: hypsometric integral; P_{max}: maximum monthly precipitation; Rpk: relief peakedness.

2. Study Area

The drainage system of Ghana is divided into three main units: the Volta Basin, South-western Basin and Coastal Basin (Figure 1). The Volta River Basin drains about three-fourths of the total land area of Ghana and consists of the following major catchments; Black Volta, White Volta, Daka, Oti, Afram, Pru, Sene, Kalurakuni and

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Lower Volta. The South-western Basin consists of the Pra,

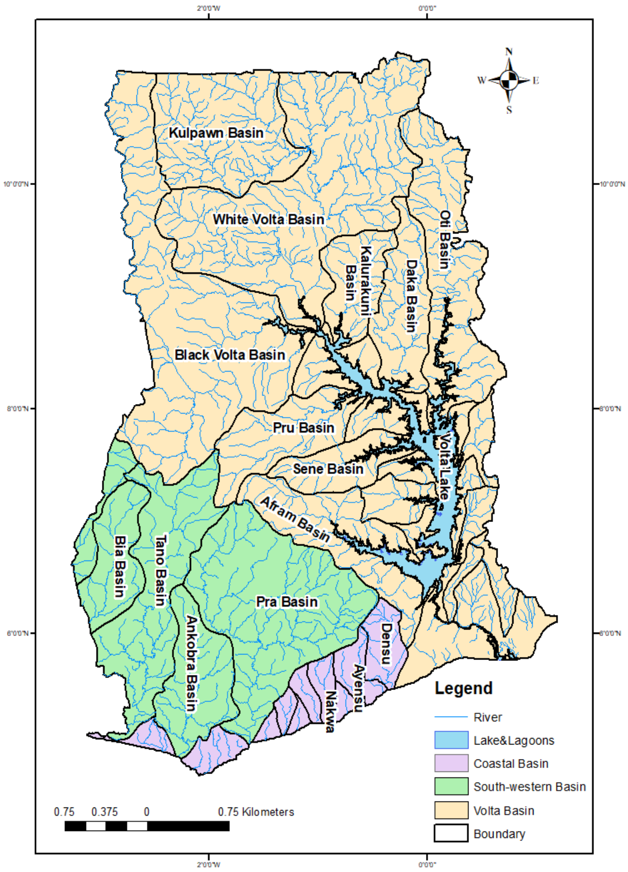

Figure 1. Map of Ghana showing the main drainage basins

Ofin, Oda and the Birim (Figure 2). The drainage basin area is 23,188 km^2 with a mean annual discharge of 214 m^3s^{-1} [42]. The basin is generally of low relief characterised by undulating topography with an average elevation of about 450 m above sea level.

The soils are forest ochrosols which are alkaline and forest oxysols which are acidic. The soils are derived from the Tarkwaian and Birrimian geological formations of sandstones, granites and metamorphosed rocks such as phyllites and schists [43].

The climate of the basin is the wet semi-equatorial climatic system which is characterized by two rainfall maxima, the first season being April - July and the second rainy season is from September - November. The rains are brought by the moist south-west monsoons with high annual rainfall amounts of between 125 and 200 cm. The rainy season could be characterised by high flows which can cause bank erosion at certain sections of the river channel. Dry seasons are well marked and span from November to March [43]. The Pra Basin is covered by the moist semi-deciduous forest vegetation which consists of trees, lianas, climbers, and shrubs/bushes which protect the soil from erosion by rain drops and run-off. Most corridors of the river channels are covered by shrubs which protects them against bank erosion [43].

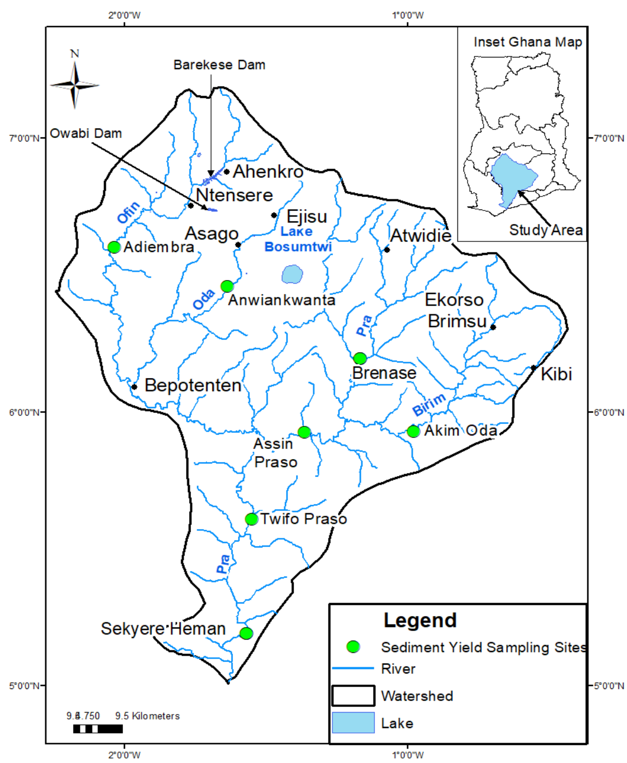

Figure 2. Pra River Basin showing sediment yield sampling sites

Ankobra, Tano and the Bia rivers. The coastal rivers include the Densu, Ayensu and Nakwa. The northern and coastal zones of the country are characterised by flat and undulating topography of a denuded landscape with isolated peaks of plateau surfaces/inselbergs which rise to 180 meters a.s.l. The middle belt of the country is however of folded mountain ranges of elevations between 240 - 300 meters a.s.l [43]. Ghana is located within the equatorial zone hence its climate is tropical; hot and humid in the south whiles the northern part is hot and dry. The rainfall regime in the north is unimodal with an annual mean of about 100 cm and bimodal in the south with an annual rainfall of about 180 cm [43]. Generally, the vegetation in northern part is grassland, middle belt is tropical forest and shrubs cover the coastal landscape.

Sediment yield analysis was carried out in the Pra River Basin which is part of the south-western basin Ghana (Figure 1) with the following geographical coordinates; latitudes 5°00'N and 7°15'N and longitudes 0°03'W and 2°80'W. The basin consists of three major sub-basins;

3. Research Materials and Methods

3.1 A Review of Sediment Yield Predictive Models in Ghana

Base on measured suspended sediment yield and discharge data on certain forested river basins in Ghana, Amisigo and Akrasi (2000) [9] derived three empirical equations (eqns. 1-3) of least square regression for the prediction of specific suspended sediment yields of catchments in the southwestern basin system for which no sediment measurements are known:

$$SSY = 9.92A^{0.062} \quad (1)$$

$$SSY = 44.9S_R^{0.773} \quad (2)$$

$$SSY = 0.24Q^{0.84}A^{0.26} \quad (3)$$

Where SSY = the mean annual specific suspended sediment yield (t km^{-2} $year^{-1}$), S_R = total annual stream flow per basin area (Q × 3600s/h × 24h/day × 365days/yr × 1/(A × $10^6 m^2/km^2$) = 31.536 km^2 s/yr.m^2 × Q/A), Q = mean daily stream discharge (m^3/s) and A = catchment area (km^2). Equation 1 had a co-efficient of determination (R^2) of 0.02, that of eqn. 2 is 0.65 and eqn. 3 is 0.95. Later Akrasi (2005) [12] again used eqn. (3) based on observed data of specific suspended sediment yield obtained for eight measuring stations in six river basins of the Volta River Basin to develop a simple empirical prediction model for estimating the specific suspended sediment yields of catchments in the Volta basin system for which no sediment measurements are available. The adjusted coefficient of determination (R^2) for the relationship was 0.92, indicating that the parameters selected by the regression analysis (mean daily stream discharge and catchment area) accounted for a large proportion of the variance of the sediment yield data and both exponents were statistically significant at 5% level. Also, the ability of eqn. 1 to predict the specific suspended sediment yields of Volta River sub-basins was further demonstrated by a plot of predicted versus observed specific suspended sediment yield for eight gauged catchments in the Volta Basin. The coefficient of determination of the observed versus predicted values was 94%. This model was later used to estimate the specific suspended sediment yields in other catchments such as the Pra, Ankobra, Tano among others in southern Ghana.

The model of Boateng et al., (2012) [6] was derived by establishing a relationship between catchment area and sediment yield to estimate fluvial sediment inputs into the coastal sediment budget in Ghana, using suspended sediment discharge data of 11 stations sampled for an average period of 12 years [20]. Two sets of equations were used: one for smaller catchments (Ss) (i.e. catchment less than 5,000km^2) eqn.4 and for large catchments (SL) (i.e. catchment more than 5,000km^2), eqn.5. This is because small catchments are often recorded as having proportionally large yields [44]. Linear regression equation was applied to large rivers because it provided the best fitted curves of graphical plot (a correlation coefficient R^2 of 0.98) and quadratic regression relationships for smaller catchments because it offered the best fit with a correlation coefficient R^2 of 0.61.

The regression equation for smaller catchments (Ss): Suspended sediment yield (SY) (t/yr) = 20722−1.127 × a + 0.001422 × a^2 … (R^2 = 0.98), ... (4) and for large catchments (SL): Suspended sediment yield (SY) (t/yr) = -108+15.80 × a.................... (R^2 = 0.61), ... (5) where A = catchment area (km^2) and t = tonnes.

3.2 Suspended Sediment Yield Measurements in the Pra River Basin

Suspended sediment concentration measurements were taken for 10 months on the Pra River and major sub-catchments of the Pra catchment (i.e Ofin, Oda and Birim) (Figure 2). Samples were taken using dip and integrated sampling approaches. Samples were analyzed using the evaporation method. Daily mean suspended sediment concentration was calculated from which monthly and annual suspended sediment yields were derived. The sampling procedure at the various stations, laboratory analysis and the method used to compute the suspended sediment yields of the sampled rivers have been well explained in Kusimi et al., (2014) [2]. Sediment rating curves using the rating techniques of Walling 1977 [45] were derived by plotting suspended sediment discharges against water discharges for each of the stations [2]. Rating curves of the stations are illustrated in Table 2. The best fit curve was that of Twifo Praso with a co-efficient of determination (R^2) of 98%.

Table 2. Suspended sediment rating curves in the Pra River Basin

No.	Station	River	Equation	R^2
1	Sekyere Hemang	Pra	$Qs = 429.48Q^{0.67}$	0.66
2	Twifo Praso	Pra	$Qs = 100.38Q^{0.90}$	0.98
3	Assin Praso	Pra	$Qs = 14.638Q^{1.12}$	0.92
4	Akim Oda	Birim	$Qs = 31.626Q^{0.95}$	0.73
5	Adiembra	Offin	$Qs = 10.914Q^{0.97}$	0.86
6	Brenase	Pra	$Qs = 31.608Q^{0.97}$	0.73
7	Anwiankwanta	Oda	$Qs = 13.676Q^{1.15}$	0.86

Note: Qs = suspended sediment discharge

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3.3 Evaluation of Existing Sediment Yield Models

Predicted sediment yields from equations 1, 3, 4, & 5 were compared with the 10 months observed sediment yields of the Pra Basin [2]. The performance of the equations was evaluated for levels of predictability base on R^2 and the root mean square errors (RMSEs) of the models. Since equation 1- 3 predict specific annual suspended sediment yield (SSY), the predicted specific annual suspended sediment yield data were converted to annual suspended sediment yield (SY) by multiplying each predicted specific annual suspended sediment yield (SSY) by the basin area (see Tables 3 - 6). Equation 2 was not used in this analysis because of the incompatibility of data format, i.e. mean daily stream discharge (m^3/s) could not be converted to total annual stream flow per basin area km^2 s/m^2. A linear regression between predicted sediment yield data derived from the models and the observed suspended sediment yields of the Pra Basin was done to determine the extent of prediction of the observed sediment yields. The co-efficient of determination (R^2) and RSMEs were derived for each model to ascertain their predictive levels (Figs.3 - 6 and Tables 3 - 6).

4. Results and Discussion

4.1 Evaluation of Sediment Yield Prediction Models

Table 3 shows catchment areas, observed sediment yields of the rivers, predicted annual specific suspended sediment yield as well as the predicted total sediment yields derived from equation 1. The predicted annual specific suspended sediment yield (SSY) ranged from 15.5 t km^{-2} y^{-1} in the Oda Basin to about 18.5 t km^{-2} y^{-1} in the Pra main catchment. Predicted sediment yields (SY) are between 19,912.9 t/yr and 420,521 t/yr. Predicted sedi-

Table 3. Sediment yields derived from equation 1

River	Station	Catchment Area (km^2)	Predicted annual specific suspended sediment yield (t km^{-2}/yr)	Predicted annual suspended sediment yield (t/yr)	Observed annual suspended sediment yield (t/yr)	Percentage of sediment under estimation	Percentage of observed sediments predicted	RMSE
Oda	Anwiankwanta	1,287.7	15.5	19,912.9	66,094.1	69.9	30.1	2,808,070.6
Offin	Adiembra	3,101.1	16.3	50,640.7	115,372.1	56.1	43.9	3,031,046.5
Birim	Akim Oda	3,104.2	16.3	50,694.3	290,775.6	82.6	17.4	3,320,045
Pra	Brenase	2,167.8	16.0	34,622.8	150,455.4	76.9	23.1	3,711,915.2
Pra	Assin Praso	9,234.8	17.5	161,359	220,907.1	26.9	73.1	4,285,896.9
Pra	Twifo Praso	20,625.3	18.4	378,795.1	2,645,002.1	85.7	14.3	5248961.4
Pra	Sekyere Heman	22,7578	18.5	420,521	7,489,290.1	94.4	5.6	7,068,769.1
	Mean			159506.5	1,568,270.9			4,210,672.1

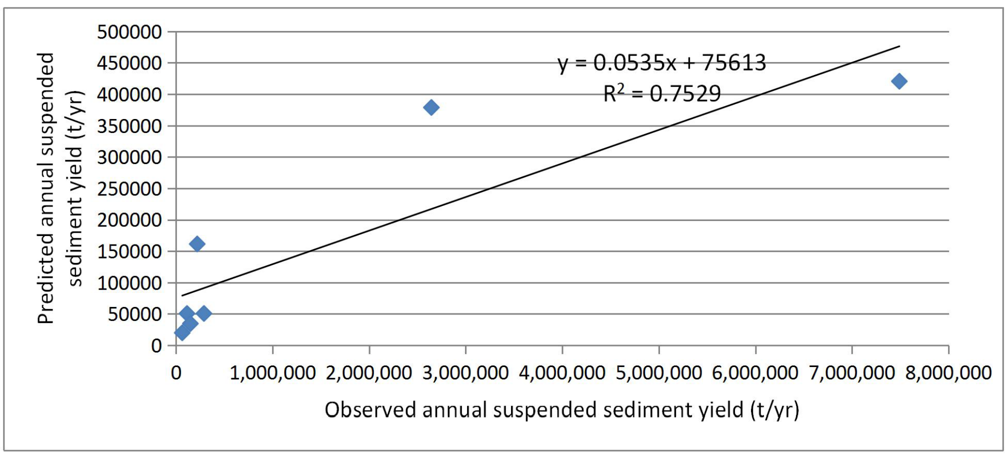

Figure 3. A plot of predicted and observed suspended sediment yields for equation 1

ment yields are lower than the observed sediment yields in all basins. The predicted suspended sediment yield was lowest 19,912.9 t/yr as against 66,094 t/yr observed in the Oda Basin at Anwiankwata and the highest predicted was 420,521 t/yr as against 7,489,290 t/yr observed in the Pra Basin at Sekyere Heman (Table 3). Equation 1 grossly underestimates sediment yields in the river basins. The percentage of under estimation of sediment yield ranges between 27-94% across the basins. The model can predict sediment yield of between 6-73% of observed sediment yield with RMSE range of 2.8-7.1 million and a mean of 4.2 million. Apart from Assin Praso where sediment yield predicted is over 70%, the percentage of sediments predicted in other basins is insignificant (Table 3). Figure 3 shows a scatter plot of predicted suspended sediment yield (t/yr) against observed suspended sedimentyield (SY) for equation 1 with a linear equation $y = 0.0535x + 75613$; $R^2 = 0.75$. Based on the co-efficient of determination, equation 1 is a good predictive model of sediment yield in the Pra River.

Estimating sediment yield using basin area in this model will result in the estimation of over 70% of annual sediment yields in the watershed.

Predicted annual specific suspended sediment yield (SSY) and predicted suspended sediment yield (SY) results derived from equation 3 is presented in Table 4. Predicted annual specific suspended sediment yield is between 14 and 660 t km^{-2} year^{-1} and annual suspended sediment yield is between 17,604 and 15 million t/yr. For equation 3, predicted sediment yields were lower than observed sediment yields in four stations whiles in the other three stations, predicted sediment yields were higher than observed sediment yields. Under estimation of sediments were at Akim Oda on the Birim River, Brenase on the Pra River, Twifo Praso on the Pra River and Adiembra on the Ofin River (Figure 2). Percentage of under estimation of sediment yield is between 13 and 94%, thus equation 3 could predict between 6 and 84% of observed sediment

Table 4. Sediment yields derived from equation 3

River	Station	Catchment Area (km^2)	Predicted annual specific suspended sediment yield (t km^{-2} year^{-1})	Predicted annual suspended sediment yield (t/yr)	Observed annual suspended sediment yield (t/yr)	Percentage of sediment under/ over estimation	Percentage of observed sediments predicted	RMSE
Oda	Anwiankwanta	1,287.7	40.9	126,858.4	66,094.1	-91.91	191.9	3,326,568.1
Offin	Adiembra	3,101.09	22.6	49,064.4	115,372.1	57.5	42.5	3,593,018.5
Birim	Akim Oda	3,104.18	13.7	17,604.3	290,775.6	93.9	6.1	3,935,842.9
Pra	Brenase	2,167.79	42.2	130,733.7	150,455.4	13.1	86.9	4,398,285.8
Pra	Assin Praso	9,234.75	206.5	4,259,705.3	220,907.1	-1828.3	1928.3	5,078,690.3
Pra	Twifo Praso	20,625.28	58.2	537,091.5	2,645,002.1	79.7	20.3	5,525,730.4
Pra	Sekyere Heman	22,757.98	659.7	15,014,189.2	7,489,290.1	-100.5	200.5	7,524,899.1
	Total			2876463.8	1,568,270.9			4,769,005

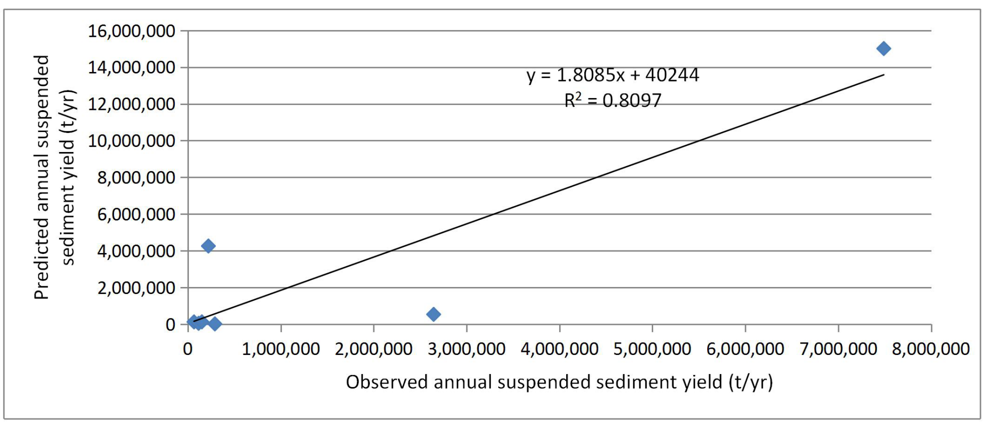

Figure 4. A plot of predicted and observed suspended sediment yields for equations 3

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yields of the respective catchments (Table 4). Predicted annual suspended sediment yields were greater than the observed yields at Anwiankwanta on the Oda River, Assin Praso and Sekyere Heman all on the Pra River (Table 4 and Figure 2). Over prediction of fluvial sediments ranges from 92 to over - 1,800% of observed data (Table 4).

Linear regression curve derived from a plot of the predicted suspended sediment yield (t/yr) against observed suspended sediment yield are shown in Figure 4. The predictive model and co-efficient of determination are y = 1.8085x + 40244 and R^2 = 0.80 with RMSEs range of 3.3 to 7.5 million. The co-efficient of determination of the curve show that the linear regression model is a good predictive model for suspended sediment yield in the Pra Basin. Equation 3 is therefore a good equation for estimating sediment yield in the Pra Basin and base on findings of Amisigo and Akrasi (2000)[9] and Akrasi (2005)[12], this model is a good estimator of sediment yield in Ghanaian rivers. Thus, basin area and water discharge are key factors to coupled in predicting river sediment load and transport in Ghanaian rivers.

Table 5 shows the suspended sediment yields predicted base on equation 4 and observed yields for each station. The lowest predicted sediment yield was 20,237 t/yr as against observed value of 66,094 t/yr at Anwiankwanta in the Oda River Basin whiles the highest values are 731,564 t/yr and 7,489,290 t/yr for predicted and observed respectively at Sekyere Heman. For equation 4, all predicted suspended sediment yields were lower than observed sediment yields. Predicted fluvial sediments are under predicted with percentage under estimation ranging from 40 - 90%. The difference between the observed and predicted ranged between 45,857 t/yr at Anwiankwanta on the Oda River to about 6.8 million t/yr at Sekyere Heman (Figure 2). Except at Assin Praso on the Pra River, fluvial sediment yields predicted are all lower than 50% of ob-

Table 5. Sediment yields derived from equation 4

River	Station	Catchment Area (km^2)	Predicted annual specific suspended sediment yield (t km^{-2} year^{-1})	Predicted suspended sediment yield (t/yr)	Observed suspended sediment yield (t/yr)	Percentage of sediment under estimation	Percentage of observed sediments predicted	RMSE
Oda	Anwiankwanta	1,287.7	15.7	20,237.7	66,094.1	69.4	30.6	2,835,926.9
Offin	Adiembra	3,101.1	15.8	48,889.2	115,372.1	57.6	42.4	3,063,093.9
Birim	Akim Oda	3,104.2	15.8	48,938	290,775.6	83.2	16.8	3,355,319.6
Pra	Brenase	2,167.8	15.8	34,143.1	150,455.4	77.3	22.7	3,749,412
Pra	Assin Praso	9,234.8	14.3	131,583.5	220,907.1	40.4	59.6	4,328,927.2
Pra	Twifo Praso	20,625.4	29.2	602,399.2	2,645,002.1	77.2	22.8	5,301,565.5
Pra	Sekyere Heman	227,578	32.2	731,564	7,489,290.1	90.2	9.8	7,129,822.1
				140464.1	1,568,270.9			4,252,009.6

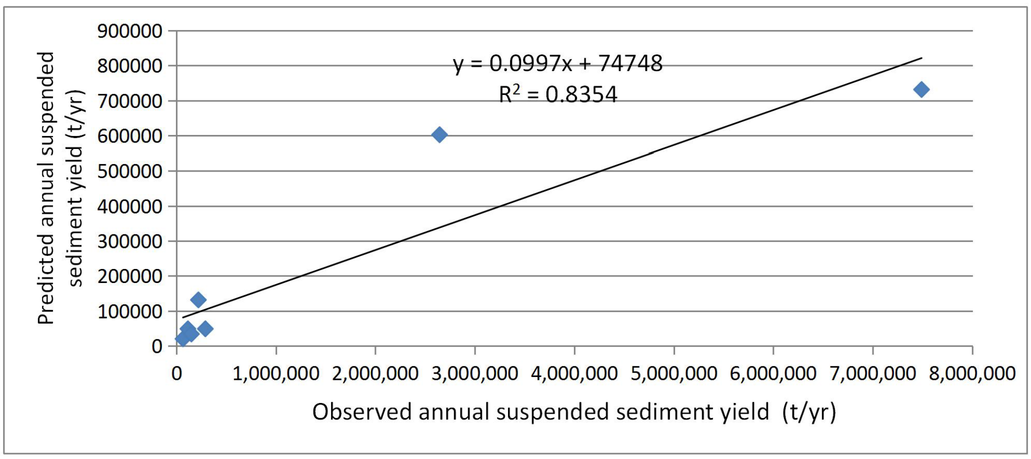

Figure 5. A plot of predicted and observed suspended sediment yields for equation 4

served sediment yield data in all other sub- basins (Table 5). Similarly, the RMSE of sediment prediction is between 2.8 and 7.1 million with average of 4.2 million. Figure 5 shows the best fit line and the co-efficient of determination between predicted and observed data of sediment yields. The co-efficient of determination of the best fit line is $R^2 = 0.84$. Equation 4 is also a good model in sediment yield estimation base on catchment area, but it is a better model than equation 1 where R^2 is 0.75 which is also base on watershed area.

Results of predicted sediment yield and the annual specific sediment yield of equation 5 are illustrated in Table 6. Predicted sediment yield ranges between 20,237 t/yr as the lowest at Anwiankwanta in Oda Basin to 3.5 million t/yr at Sekyere Heman in the Pra River Basin with an average annual specific sediment yield of about 15.8 t km^{-2} year^{-1} across all basins. Like equation 4, observed suspended sediment yields were higher than all predicted suspended sediment yields. For instance, observed sediment yield was 290,775 t/yr as compared to 48,938 t/yr predicted in Akim Oda (Table 6). The level of under prediction of fluvial sediment transport was high. The difference in sediment yield between predicted and observed data is between 45,857 t/yr at Anwiankwanta and 7.1 million t/yr at Sekyere Heman (Figure 2). Equation 5 predicts between 5 and 66% of observed fluvial sediment transport and just like equation 4, the amount of fluvial sediments predicted are all less than 50% of observed data except at Assin Praso (Table 6). Also, the RMSEs are equally like results of equation 4. A plot of predicted annual suspended sediment yield for equation 5 against observed annual suspended sediment yield in the Pra River Basin is shown in Figure 6. The co-efficient of determination of the linear regression is $R^2 = 0.75$. For Boateng et al., (2012) [6] equations; equation 4 is a better estimator of sediment yield compared to equation 5 since the co-efficient of determination of equation 4 is higher (0.84%). Equation 5 also produces similar RMSEs as other equations (Table 6).

For all the sediment yield predictive models, the lowest results were obtained in the Oda Basin and the highest

Table 6. Sediment yields derived from equation 5

River	Station	Catchment Area (km^2)	Predicted annual specific suspended sediment yield (t km^{-2} year^{-1})	Predicted suspended sediment yield (t/yr)	Observed suspended sediment yield (t/yr)	Percentage of sediment under estimation	Percentage of observed sediments predicted	RMSE
Oda	Anwiankwanta	1,287.7	15.7	20,237.7	66,094.1	69.4	30.6	2,835,926.9
Offin	Adiembra	3,101.1	15.8	48,889.2	115,372.1	57.6	42.4	3,063,093.9
Birim	Akim Oda	3,104.2	15.8	48,938	290,775.6	83.2	16.8	3,355,319.6
Pra	Brenase	2,167.8	15.8	34,143.1	150,455.4	77.3	22.7	3,749,412
Pra	Assin Praso	9,234.8	15.8	145,801.1	220,907.1	34	66	4,328,927.3
Pra	Twifo Praso	20,625.4	15.8	325,771.4	2,645,002.1	87.7	12.3	5,301,565.5
Pra	Sekyere Heman	227,578	15.8	3,594,68.1	7,489,290.1	95.2	4.8	7,129,822
	Mean			140464.1	1,568,270.9			4,252,009.6

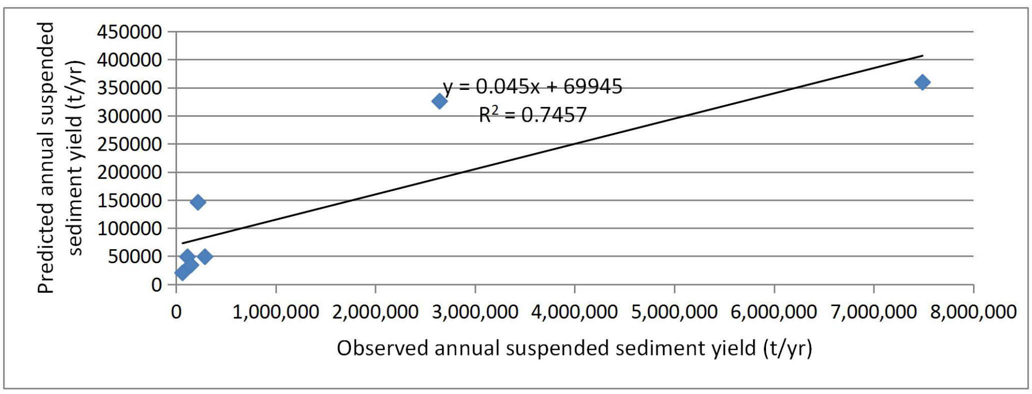

Figure 6. A plot of predicted and observed suspended sediment yields for equation 5

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Table 7. Sediment yields of equation 3 base on only water discharge

River	Station	Water Discharge (m^3/s)	Predicted annual suspended sediment yield (t/yr) with discharge and area	Predicted suspended sediment yield (t/yr) with on only discharge	Percentage of water discharge sediments
Oda	Anwiankwanta	37.61	17,604.3	5.1	0.004
Offin	Adiembra	20.8	130,733.7	3.1	0.006
Birim	Akim Oda	13.41	126,858.4	2.1	0.012
Pra	Brenase	39.04	49,064.4	5.2	0.004
Pra	Assin Praso	144	537,091.5	15.6	0.0004
Pra	Twifo Praso	40.85	4,259,705.3	5.4	0.001
Pra	Sekyere Heman	556.67	15,014,189.2	48.6	0.0003

values in the Pra main catchment at Sekyere Heman for both annual specific suspended sediment yield and annual suspended sediment yield. It is observed that sediment yield tends to increase as the drainage basin increases, thus basins of larger areas yield higher sediments. Estimating the sediment yield of equation 3 with only water discharge (Table 7) shows that, water discharge accounts for less than 0.1% of predicted sediment yields of the equation. Thus over 99.9% of the sediments estimated by equation 3 in Table 4 are attributable to catchment area. Catchment area is therefore a key independent predictive variable in sediment yield estimation in the Pra Basin. This finding is however at variance with other studies where sediment yield decreases with catchment area [2, 4, 38, 46-48]. The explanation to this phenomenon is that an increase in catchment area increases the probability of sediment deposition owing to decreasing slope and channel gradients. Comparing R^2 and RMSEs of the models, the best sediment yield predictive equation is equation 4 which had R^2 of 0.84 followed by equation 3 ($R^2 = 0.80$) with equations 1 and 5 being the least having R^2 of 0.75. Generally, most predicted values of fluvial sediment yields are lower than observed sediment yields in all the catchments. The RMSEs are equally similar for all models except that of eqn.3.

5. Conclusion

The prediction of suspended sediment yield was done for 4 out of the 5 known sediment yield predictive models in Ghana. There were variations in sediment yield between observed and predicted suspended sediments. Predicted sediment yields of equation 3 were found to be higher and lower than the observed sediment yields in certain basins; however predicted sediment yields of equations 1, 4 and 5 were all lower than that of observed suspended sediment yields. For all the sediment yield predictive models, the lowest results were obtained in the Oda Basin and the highest values in the Pra main catchment at Sekyere Heman for both annual specific suspended sediment yield and annual suspended sediment yield. The analyses showed that sediment yield increases with drainage basin area, thus basins of larger drainage areas yield higher sediments. Based on co-efficient of determination (R^2), all the sediment yield models evaluated can be said to be good estimators of sediment yield for river basins in Ghana.

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ARTICLE

County-level USA: No Robust Relationship between Geoclimatic Variables and Cognitive Ability

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ABSTRACT

Using a sample of ~3,100 U.S. counties, we tested geoclimatic explanations for why cognitive ability varies across geography. These models posit that geoclimatic factors will strongly predict cognitive ability across geography, even when a variety of common controls appear in the regression equations. Our results generally do not support UV radiation (UVR) based or other geoclimatic models. Specifically, although UVR alone predicted cognitive ability at the U.S. county-level (β = -.33), its validity was markedly reduced in the presence of climatic and demographic covariates (β = -.16), and was reduced even further with a spatial lag (β = -.10). For climate models, average temperature remained a significant predictor in the regression equation containing a spatial lag (β = .35). However, the effect was in the wrong direction relative to typical cold weather hypotheses. Moreover, when we ran the analyses separately by race/ethnicity, no consistent pattern appeared in the models containing the spatial lag. Analyses of gap sizes across counties were also generally inconsistent with predictions from the UVR model. Instead, results seemed to provide support for compositional models.

1. Introduction

It is well-established that cognitive ability varies across geopolitical divisions such as nations, states, and counties (e.g., nations: [1-2]; Vietnamese provinces: [3]; U.S. states: [4]; U.S. counties: [5]; Argentinian provinces: [6]). These cognitive ability differences have frequently been quite large. Using the fifty U.S. states as an example, the difference between the lowest (Mississippi) and highest (Massachusetts) scoring state was found to be 10.1 IQ-metric points (henceforth just IQ points) [4]. Moreover, these aggregate-level cognitive ability differences have often correlated strongly with other important outcomes including income [7] and education levels [8], health and wellness [9], and rates of various crimes [10].

Although aggregate cognitive scores are potent predictors of important social, economic, and political outcomes [11], consensus about why these relationships exist and for why cognitive ability varies across geography has been lacking. Notably, a recently conducted survey of researchers in this area revealed belief in several potential causes for aggregate cognitive variation including differ-

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ences in education (both quantity and quality), genetics, health, and wealth [12]. Of particular interest for the present study, the surveyed experts generally considered current climate and geography to have relatively small causal effects (only 1 to 3% of the total); nearly all of the experts seemed to dismiss the contemporary effects of climate as a major contributing variable for geospatial differences in cognitive ability.

Despite this, cognitive ability and other behavioral traits show a latitudinal gradient. This led Van der Vliert and Van Lange [13] to propose "latitudinal psychology"; as they note, there are "north-south gradients in cognitive ability, creativity, ingroup-outgroup dynamics, aggressiveness, life satisfaction, and individualism versus collectivism" (p. 43) which need to be accounted for. Indeed, in their review, Lynn et al. [11] reported that 12 of 15 countries exhibited a positive association between absolute latitude and cognitive ability. These intra-country cognitive clines in latitude mirror an international one [14]. Related latitudinal behavioral clines can be found among geographically dispersed non-human animals [13].

Geo-climatic models are in line with the traditional view that latitude-related differences in human behavior are in part caused by the direct effects of ecological and geoclimatic factors [15]. In line with this paradigm, geoclimatic variables have been offered to explain differences in cognitive outcomes (e.g., cognitive ability, future orientation, innovation, state intelligence, educational attainment). Specific latitude-associated causal factors include cold weather ([16-17]; see, relatedly, [18,19,13,20]), latitude-dependent infectious disease ([21-23]), and ultraviolet radiation (UVR) ([21,24-27]; also [13]). These variables may share overlapping causal pathways. Unlike typical sociocultural factors (e.g., socioeconomic status, family values, quality of school curriculum), they are proposed primarily to account for regional variation, and less so for individual variation within regions since the effects of the proposed causal factors are geographically stratified.

The most extensively developed model with respect to cognitive ability specifically is that of Federico León and colleagues. They have argued that geographic differences in UVR have important effects on cognitive ability which are unmediated by genetics. Unlike other UVR models where UVR indexes behaviorally-relevant evolutionary pressures (e.g., [28-29]), this is an environmental model. León et al. have proposed three complementary pathways through which UVR might act on aggregate cognitive ability ([21,24,25-27]). The first pathway involves high UVR exposure exerting an amplifying effect on sex hormone production and fertility which then reduces parental investment in offspring cognitive capital accumulation. The second pathway supposes that UVR exposure increases oxidative stress which is purported to be related to both cognitive impairment and fatigue. The final pathway invokes a supposed immunosuppressive effect of UVR which is claimed to increase disease susceptibility. The implication is that in high UVR regions it may be necessary to divert energy from brain development to the immune system, although it's also possible that the direct effect of developmental insults from disease via increased exposure and vulnerability could be explanatory. Based on a literature review, Meisenberg [30] determined that the UVR model was plausible. However, it is notable that, contrary to this model, low Vitamin D, rather than high is associated with cognitive problems [31].

León and colleagues have tested their model in cross-sectional designs using regression and/or path models globally [32], across Europe [33], in the U.S. ([21,27,34,35]), Brazil [35], Italy [35], and Peru [36]. To date, their analyses have indicated UVR has predictive validity for cognitive ability and socioeconomic outcomes even in the presence of several plausible confounders such as ethnicity, absolute latitude, and temperature.

This geoclimatic research programme has several notable shortcomings. First, all analyses thus far have been conducted at the national or subnational level, not the individual level. It has not been shown that increased UVR exposure is associated with decreased cognitive ability for individuals. Second, the regional and national sample sizes have typically been small (though not always; see, e.g., [36]). For example, in the five U.S. studies examining the UVR-cognitive ability relationship at the state level, the Ns ranged from 48 to 50. For Italy, Brazil, Europe, and globally, sample sizes were 19, 26, 32, and 194, respectively. However, multivariate statistics were used to analyze the data. This could result in imprecise parameter estimates when the variables are strongly intercorrelated, as they usually are with highly aggregated data [10]. Third, spatial autocorrelation (SAC) issues are abundant in national and subnational geographic data ([37-39]) but León and colleagues have not taken these into account (excepting one case; [34]). Unmodeled SAC has the potential to bias results due to unmeasured spatially autocorrelated confounders. SAC diminishes the precision of studies since OLS standard errors assume independent data points whereas SAC induces dependencies among them such that errors can be correlated when autocorrelated causes are unmodeled (assuming the causes themselves are autocorrelated). Finally, some research has found that results may be discordant across levels of analysis [40]. For example, U.S. state-level results may not match U.S. county-level results [41]. For this reason, in their review of regional dif-

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ferences in intelligence, Lynn et al. [11] urged authors to examine data at multiple levels in order to ensure robustness.

The main goal of the present study was to alleviate the shortcomings described above, in part by analyzing data at the U.S. county-level. There are many more U.S. counties than there are U.S. states, which allowed us to conduct multivariate analyses avoiding sample size concerns. Additionally, we were able to compare state- and county-level results, and we were able to include spatially lagged variables which allowed us to address the issue of SAC. An advantage of this dataset was that, owing to replacement migration, geography was less confounded with evolutionary history [42]. Thus, geoclimatic effects can be more readily interpreted as representing contemporaneous effects, as opposed to evolutionary ones (e.g., [43]). Importantly, however, these sorts of relationships can also result from processes aligning demography with evolutionarily familiar or novel environments, or from migratory self-selection ([34,44-45]).

A final goal of the present study was to evaluate the UVR and other geoclimatic models (i.e., latitude and cold weather), as advocated by León [21] and others, versus an ethnic composition model, as suggested by, for example, McDaniel [4]. McDaniel [4] argued that U.S. state cognitive differences were in part a result of demography, conjecturing that the regional differences would be stable so long as the racial demographics (and, also, mean self-identified race and ethnicity (SIRE) differences) were. Conversely, León [22] argued that the association between state cognitive ability and racial composition was spurious. That is, the association was due to the distribution of whites in states with low levels of UVR. The reason for testing a racial/ethnic compositional model is that León and Hassall [34] clearly specified this as an alternative to their geoclimatic model for U.S. regional differences. To be clear, though, racial/ethnic compositional models only attempt to account for regional differences in terms of demographics given known racial/ethnic trait differences. They do not attempt to account for the origins of racial/ethnic differences, which ultimately could be due to culture, genetics, or other factors (for expert opinion on cognitive ability differences see: [12], [46]). The point of these analyses is to see if previously found associations between geoclimatic variables and cognitive ability, in the U.S., can be statistically explained by demographic confounding.

2. Method

The analytic strategy involves running regression models with geoclimatic factors (average temperature and UVR) and proxies for these (latitude, longitude, and elevation) as predictors of county-level cognitive ability. While geoclimatic effects can be interpreted as representing contemporaneous effects on cognitive ability, they could also represent evolutionary effects on ability (e.g., [28],43]) because migration and settlement patterns in the U.S. and other New World countries have not been random ([34]). Moreover, since ancestral populations differentially adapted to geoclimatic effects over evolutionary time (e.g., pigmentary, thermoregulatory, and disease-related adaptations in response to UVR, climatic, and parasite load-related effects [28-29]), contemporaneous geoclimatic effects may be modified by the racial/ethnic composition of a population. For example, in the UVR model, UVR is proposed to act through hormones, including vitamin D; however, perhaps owing in part to skin tone differences, there are well-known vitamin D level differences between U.S. racial/ethnic groups [47]. Thus, we included race/ethnicity variables as predictors, since these act as crude measures of genetic ancestry and the related evolutionary environments ([48-49]); we also run analyses separately by SIRE group.

Beyond race/ethnicity, we added a spatial lag to capture effects of both SAC and unobserved variables. In the supplement, we detailed with simulations how including a spatial lag confers the added benefit of controlling for unmodeled variables ([50-51]). We do not include socioeconomic status as an independent variable in our regression models since these add no analytic leverage when it comes to evaluating geoclimatic models. This is because geographic differences in socioeconomic status is another outcome which geoclimatic models are invoked to explain (e.g., [13,27]). Also, with the current dataset, it is difficult to disentangle the causal relation between socioeconomic status and cognitive ability. As such, we report results with socioeconomic status as the dependent variable for the main analysis. This is because socioeconomic status could be treated as an alternative measure of county-level functioning. Since our primary concern, following León et al. is with measured cognitive ability that is our primary focus.

We used R 3.6.1 for the analyses. All code and data have been made publicly available in the supplementary materials.

2.1 Measures

2.1.1 County Cognitive Ability

We used data from the Stanford Education Data Archive (SEDA v3.0; [52]), which was publicly available at https://cepa.stanford.edu/seda/overview. This resource contained cognitive testing data from many sources in-

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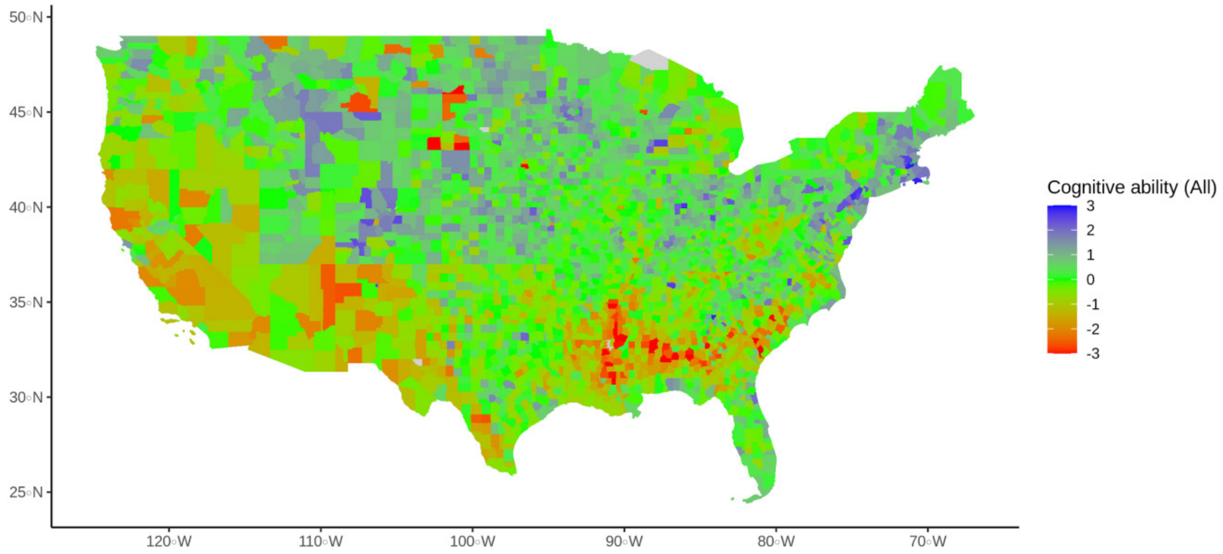

Figure 1. Map of county-level cognitive ability

Note: The scale refers to county-level standardized units, where zero is the mean for all counties.

cluding NAEP and state tests which had been normed to the same scale. The data were available at the U.S. county level for the years 2009-2015. These scores were based on low-stakes math and reading/language tests given to students in grades 3-8. We used the pooled file which had precalculated scores averaged across subjects (math and language), year (2009-2015), and grade (3-8) (seda_county_pool_CS_v30). A detailed description of the method used to compute these is provided by Fahle et al. [53].

The SEDA cognitive scores are based on national and state-level achievement tests. The national tests are The National Assessment of Educational Progress (NAEP) exams. These have been found to relate to measures of intelligence, though they seem to have a greater affinity for crystallized intelligence measures. Regarding these measures, Rindermann and Thompson [54] noted: "Both NAEP scales together measure a mixture of general intelligence and specific knowledge, covered by the construct cognitive ability…. However, compared to figural scales as the Ravens, NAEP scales are more measures of crystallized knowledge." These scores have frequently been used in the intelligence literature as measures of state-level cognitive ability (e.g., [4]). Each state additionally administers state-level assessments (e.g., California Assessment of Student Performance and Progress, Iowa Test of Basic Skills, Ohio's State Test, and Washington Assessment of Student Learning). These have been evaluated, both qualitatively and quantitatively, by the U.S. Department of Education, for the purpose of linking state and national data ([55-59]). Results for the NAEP state assessment mapping analyses can be accessed at https://nces.ed.gov/nationsreportcard/studies/statemapping. The specific methods used by the SEDA for linking the NAEP and state-level tests are detailed on the Educational Opportunity Project website, which can be accessed at https://edopportunity.org/methods. In their validity report, Reardon, Kalogrides, and Ho [60] report correlations of > .90 between the linked district-level scores based on state tests and those based on the NAEP for those school districts involved in the Trial Urban District Assessment and Measure of Academic Progress.

To note, we were unable to assess measurement invariance for these instruments so we cannot make strong psychometric claims about the differences. These may represent general cognitive ability differences or differences in verbal and math abilities (which are stratum I abilities in the three-stratum Cattell–Horn–Carroll model) independent of g. The issue is not immediately relevant to the hypotheses being investigated and it is unlikely that there is bias given the consistent lack of bias in other U.S. samples.

Figure 1 is a map of the distribution of average cognitive ability in our dataset, with zero as the mean for all counties and each unit increase representing an increase in one county-level standard deviation (equivalent to 3.6 individual-level IQ points). Consistent with state-level results, the preponderance of low-scoring counties could be found in the southeast and southwest. Additionally, there were low-scoring counties scattered across the Midwest and west which corresponded to Indian reservations and other counties with high percentages of native Americans.

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2.1.2 County Socioeconomic Status

The SEDA dataset also included several important covariates for research use. Among these were precomputed measures of socioeconomic status based on six indicators, including: (1) median family income, (2) the proportion of adults with a bachelor's degree or higher, (3) the proportion of unemployed adults, (4) the household poverty rate, (5) the proportion of households receiving SNAP benefits, and (6) the proportion of households with single mothers. The component loadings and descriptive statistics for the SES indicators are shown in Table 1 below.

Table 1. Descriptive statistics and component loadings for the SES indicators.

Variable	Loadings	Mean	SD
Median Family Income	0.904	10.90	0.33
Adults with BA or higher	0.721	0.28	0.14
Unemployed adults	-0.921	0.20	0.11
Household poverty rate	-0.925	0.12	0.72
Households receiving SNAP	-0.778	0.10	0.04
Households with single mothers	-0.805	0.20	0.08

Importantly, the SES scores provided here were computed for each race/ethnicity as well as for the overall population in the same way as the cognitive scores were, thus allowing for comparison of values within groups. Figure 2 is a map of the distribution of average SES in our dataset. As seen, the distribution of county-level SES parallels that of cognitive ability.

2.1.3 Demographics

The SEDA covariate files (SEDA v3.0; [52]) provided self-identified race and ethnicity (SIRE) composition data for students (e.g., "percent Whites in the grade"). These proportions are based on the 2006-2010 Common Core of Data (CCD). The CCD is an annual survey of all public elementary and secondary schools. These percentages were somewhat different from the county population percentages based on the American Community Survey (ACS). This was because they represented the percent of students in public schools, not the percentage of adults in the county. We used the CCD values since the percentage of students was the more relevant indicator for controlling the effect of school demographics on student test scores.

2.1.4 Cognitive and SES SIRE Gaps

The SEDA data file provided precomputed cognitive and composite socioeconomic SIRE standardized differences for each county. Black/White, Hispanic/White, and Asian/White *d* values were available. Standard errors for the *d* values were also provided, the inverse of which were used as analytic weights. Note, SEDA's SES *d* values

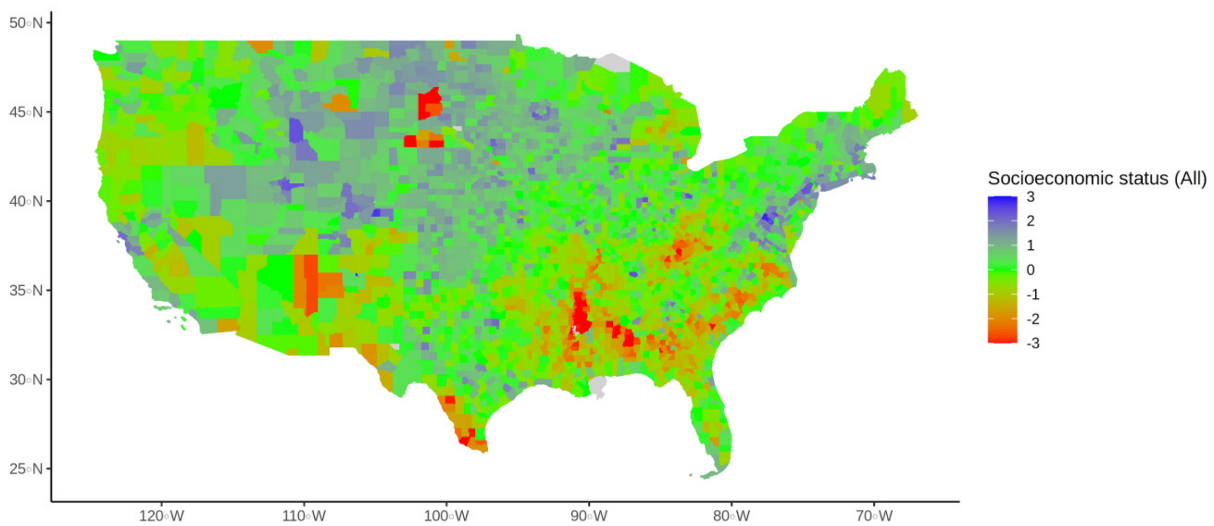

Figure 2. Map of county-level socioeconomic status

Note: The scale refers to county-level standardized units, where zero is the mean for all counties.

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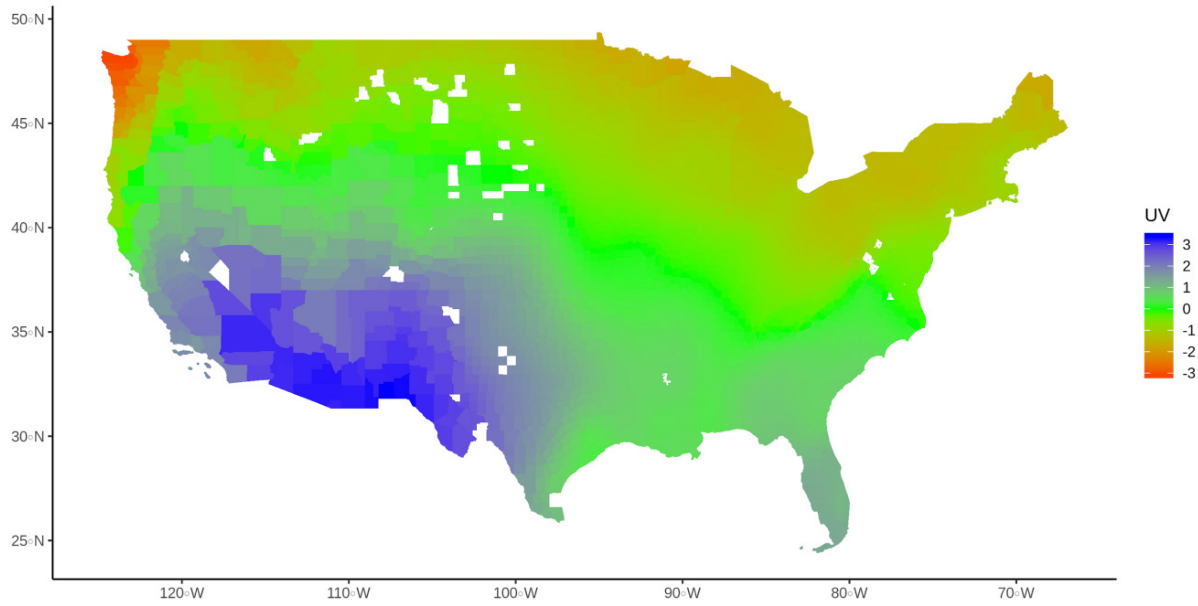

Figure 3. Map of county-level UVR

Note: The scale refers to county-level standardized units, where zero is the mean for all counties

were based on SES composite variables.

2.1.5. Ultraviolet Radiation and Climate Data

Our primary geoclimatic variables are UVR, average temperature, latitude, longitude, and elevation. The National Cancer Institute [61] provided county UVR levels measured in units of Wh/m². These were based on a 30-year average (1961-1990). Figure 3 is a map of the distribution of average UVR, standardized at the U.S. county level. Additionally, the Centers for Disease Control and Prevention [62] provided averaged yearly county-level temperature (yearly mean °C). These were based on data collected from 1979-2011.

León and colleagues have pointed out that absolute latitude is an imperfect proxy for UVR. While these variables covary very strongly at the national level (r = -.89, unweighted, our calculation), there are some sizable deviations, especially when looking at subnational data. Case in point, in our dataset, while the correlation between UVR and latitude was strong (r = -.74, unweighted; absolute values were unneeded because all values had the same sign), New Orleans county (which contained the city of New Orleans) in Louisiana lies at latitude 30.1, and has a UVR level of 0.54 (i.e., a bit above average), while Salt Lake county (which contained Salt Lake City) in Utah lies at latitude 40.9 but has a UVR level of 0.63. There are several reasons for the discrepancies between latitude and UVR including cloud coverage, ozone layer thickness (which partially blocks UVR) and altitude (with higher UVR levels at higher altitudes because of less atmospheric air for the sun's rays to pass through). In the U.S., these factors varied longitudinally and, as a result, Rocky Mountain regions tended to have higher UVR levels than eastern ones at the same latitude [21].

To capture unmeasured geoclimatic factors we included latitude, longitude, and elevation (altitude). Latitude is included since Van der Vliert and Van Lange [13] argued that latitude gradients explained geographic variability in behavior and were an important tool for the behavioral sciences. Longitude was included since León [24] argued that it was yet another dimension along which UVR acts. Elevation was included since this was a component in Cabeza de Baca and Figueredo's [63] brumal (i.e., cold) factor, which was constructed based on temperature, latitude, and altitude. The brumal factor played a central role in Cabeza de Baca and Figueredo's [63] human cognitive ecology model, according to which cold weather and higher altitudes were to be positively associated with cognitive ability. Additionally, according to León and Avilés [36], higher altitude should be related to cognitive ability, though negatively so, owing to increased UVR. Finally, for each county's latitude and longitude, we coded the U.S. census internal point. This is approximately the same as the centroid of the geographical unit, except for cases where the centroid does not lie inside the polygons(s) of the unit, in which case the closest internal point was chosen. Van der Vliert and Van Lange [64] additionally proposed steady rain as a "remote climatic predictor". However, the type of mediating effects noted (e.g., droughts, flooding, landslides) are not realistic causes of social and behavioral differences between U.S. counties so we did not include them in our analyses. As a robustness test, we ran the model with additional variables from the Center for Disease Control's reported major communicable diseases (tuberculosis, HIV, respiratory infections, hepatitis, meningitis, and diarrheal diseases) since León et al. sometimes include them in their models. However, as these variables did not substantially alter the other relations, and as they suffer from endogeneity problems (being a partial consequence of cognitive differences), we did not report these results but nonetheless provided them in the supplement.

2.1.6 Spatial Lag

Hassall and Sherratt [38] raised concerns about confounding due to spatial autocorrelation (SAC). Thus, we calculated a spatial lag term for each county by averaging the cognitive ability scores for each of the county's three closest counties (termed k-nearest spatial neighbor regression with $k = 3$). We used the three nearest neighbors as this was shown in a prior study to produce the most interpretable results [65]. For the SIRE specific regressions, the lag variable was computed based on the cognitive scores for the specific SIRE groups.

3. Results

3.1 Descriptive Statistics, Bivariate Correlations and Main Regression Results

The descriptive statistics for the variables used in the main regression analyses are reported in Table 2. When noted, we reported the descriptives for the original variables, before standardizing them for the regression analyses. This allowed comparison with individual differences since county and individual cognitive differences were on the same scale. For example, Figure 1 shows a range of 6 county-level standard deviations; this is equal to a range of 6 county level *SD* x .24 (i.e., the *SD* of CA_all) or 1.44 individual level ones (21.6 IQ points). To note, the availability of cognitive and SES scores varied by SIRE group. This is because scores were suppressed if the total number for a subgroups was less than 95% of the total reported for all students.

Table 2. Descriptive statistics for variables used in tables 3, 4, 5, and 7

	N	Mean	SD	Median	Min	Max
CA_all	3134	-0.03	0.24	-0.02	-1.20	0.66
CA_Asian	1483	0.34	0.33	0.35	-1.60	1.40
CA_Black	2135	-0.42	0.21	-0.43	-1.20	0.26
CA_Hispanic	2647	-0.25	0.20	-0.25	-0.87	0.57
CA_White	3112	0.10	0.21	0.11	-0.97	0.94
SES_all	3124	-0.08	0.69	-0.03	-3.60	1.86
SES_Black	2108	-1.95	0.86	-2.00	-4.60	1.10
SES_Hispanic	2624	-0.81	0.50	-0.82	-3.60	1.31
SES_White	3099	0.36	0.55	0.37	-2.20	2.42
% White	3124	0.72	0.25	0.81	0.00	1.00
% Black	3124	0.12	0.20	0.02	0.00	1.00
% Hispanic	3124	0.12	0.17	0.05	0.00	1.00
% Asian	3124	0.01	0.03	0.01	0.00	0.59
% Amerindian	3124	0.03	0.10	0.00	0.00	0.99
UVR	3106	4304.05	420.88	4300.00	3000.00	5722.54
Avg temp	3105	17.94	4.92	18.00	3.90	30.61
Latitude	3140	38.45	5.29	38.00	20.00	69.45
Longitude	3140	-92.27	12.90	-90.00	-180.00	-67.61
Elevation	3075	383.34	443.33	240.00	0.00	3096.16

Note:
[1]The descriptive statistics for the original variables are reported; in the regression models, these were standardized.

Table 3 shows bivariate correlations between all study variables. The unweighted correlations are reported below the diagonal. The correlations weighted by the square root of county population size are reported above. Moderate relationships existed between climatic variables and cognitive ability. UVR, by itself, correlated at $r = -.33$ (weighted) with cognitive ability. These correlations were in the directions predicted by the respective geoclimatic models. The correlations for latitude and temperature with cognitive ability were $r = .33$ and $r = -.42$ (weighted), respectively. All three geoclimatic variables were strongly correlated ($r > |.70|$). To be clear, these were aggregate-level or ecological correlations, which are usually inflated relative to individual-level ones [40].

To clarify the predictive validity of the variables we

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Table 3. Correlation matrix (weighted above the diagonal and unweighted below)

	CA_All	CA_Asian	CA_Black	CA_Hispanic	CA_White	SES_All	SES_Black
CA_all (3134)	1.00	.45	.67	.60	.76	.73	.43
CA_Asian (1483)	.48	1.00	.31	.39	.53	.25	.25
CA_Black (2135)	.65	.34	1.00	.54	.47	.46	.50
CA_Hispanic (2647)	.61	.39	.59	1.00	.42	.24	.24
CA_White (3112)	.69	.59	.40	.35	1.00	.58	.40
SES_all (3124)	.75	.33	.43	.25	.61	1.00	.65
SES_Black (2108)	.42	.31	.55	.24	.41	.65	1.00
SES_Hispanic (2624)	.34	.29	.27	.35	.33	.56	.55
SES_White (3099)	.40	.44	.21	.08	.76	.73	.56
UVR (3106)	-.37	-.05	-.17	-.16	-.11	-.20	.12
Avg temp (3105)	-.39	.07	-.19	-.03	-.13	-.34	.02
Latitude (3140)	.31	-.13	.13	-.03	.10	.33	.01
Longitude (3140)	.20	.31	.12	.31	.11	-.06	-.15
Elevation (3075)	.05	-.18	.11	-.07	-.02	.12	.08
	SES_Hispanic	SES_White	UVR	Avg temp	Latitude	Longitude	Elevation
CA_all (3134)	.28	.37	-.33	-.42	.33	.08	.13
CA_Asian (1483)	.24	.33	-.07	.05	-.13	.33	-.14
CA_Black (2135)	.22	.20	-.25	-.32	.27	.06	.14
CA_Hispanic (2647)	.28	.10	-.17	-.07	.04	.25	-.09
CA_White (3112)	.29	.65	-.10	-.20	.19	-.01	.11
SES_all (3124)	.50	.73	-.19	-.41	.39	-.15	.24
SES_Black (2018)	.50	.50	-.02	-.12	.15	-.09	.14
SES_Hispanic (2624)	1.00	.46	.05	.01	.00	-.05	.05
SES_White (3099)	.50	1.00	.08	-.12	.20	-.21	.20
UVR (3106)	.10	.06	1.00	.73	-.73	-.34	.30
Avg temp (3105)	.08	-.05	.77	1.00	-.92	.06	-.34
Latitude (3140)	-.07	.08	-.75	-.93	1.00	-.29	.23
Longitude (3140)	-.09	-.08	-.42	-.10	-.09	1.00	-.56
Elevation (3075)	.02	.02	.25	-.27	.18	-.41	1.00

Note: N in parentheses; pairwise deletion fit several regressions, as shown in Table 4. Results were weighted by the square root of population size and standardized betas (β) were used. We ran seven models. Model 1 contained UVR only, while Model 2 had SIRE only. Model 3 included both UVR and SIRE. Model 4 added covariates including temperature, latitude, longitude, and elevation. Model 5 added the spatial lag variable. Model 6 added a spline for UVR to capture nonlinear effects (restricted cubic using the *rcs*() in rms package; Harrell [68]). Finally, Model 7 added interaction terms between UVR and SIRE since León and Hassal [34] predicted them due to differences in pigmentation between groups.

Although UVR had a moderate relationship with cognitive ability by itself (Model 1, β = -.33), the relation shrank by about 50% when demographic and climatic covariates were added (Model 4, β = -.16). It dropped further in Model 5 when the spatial lag variable was included (Model 5, β = -.10). In this model, temperature had a moderate effect ($\beta_{temperature}$ = .35), however, it was in the wrong direction relative to contemporaneous climatic model predictions according to which cold climate is hypothesized to be causally associated with higher cognitive ability. Additionally, latitude, longitude, and elevation had small to medium positive effects (β= .17 to β= .24).

Allowing for nonlinear effects via a spline of UVR did not add much to the model (Model 5→6, R^2 gain = .001). Adding interaction terms for UVR and demographics resulted in a small model improvement (Model 5→7, R^2 gain = .019), but also resulted in a *positive* main effect for UVR (Model 7, β = .09). This pattern of results suggested

Table 4. County-level regression results for cognitive ability

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
	β	β	B	β	B	β	B
Intercept	.09***	.13***	.10***	.09***	.07***	.00	.08***
UVR	-.33***		-.11***	-.16***	-.10***	(nonlinear)	.09*
% Black		-.56***	-.53***	-.59***	-.52***	-.53***	-.57***
% Asian		.14***	.18***	.24***	.21***	.21***	.23***
% Hispanic		-.33***	-.29***	-.25***	-.27***	-.26***	-.24***
% Amerindian		-.39***	-.35***	-.31***	-.28***	-.29***	-.29***
Avg_temp				.39***	.35***	.34***	.19***
Latitude				.27***	.17***	.22***	.13**
Longitude				.35***	.24***	.27***	.23***
Elevation				.30***	.22***	.21***	.15***
CA_lag					.28***	.27***	.26***
UVR * % Black							.10***
UVR * % Asian							-.08***
UVR * % Hispanic							-.03**
UVR * % Amerindian							-.03
R2 adj.	0.135	0.426	0.455	0.524	0.574	0.575	0.593
N	3099	3122	3093	3062	3062	3062	3062

Note:
*Weighted by the square root of population size. Values in parentheses are standard errors. * <.01, ** < .005, *** <.001. Model 1: UVR; Model 2: SIRE groups; Model 3: UVR + SIRE groups; Model 4: Model 3 + average temperature & latitude, longitude, and elevation; Model 5: Model 4 + spatial lag; Model 6: Model 5 + spline of UVR; Model 7: Model 6 + UVR*SIRE interactions.*

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that UVR was either not a cause of cognitive ability, its effects were modified by the included covariates, or it had heterogeneous and difficult to isolate causal pathways.

The models without the spatial lag predictor showed some degree of SAC in the residuals, indicating the presence of unmodeled covariates possibly biasing estimates. This was removed after the addition of the spatial lag variable. From the pattern in the model R^2 values, it appeared demography was the main source of validity. This conclusion was confirmed by calculating partial R^2 values for the models and then calculating the proportion of total R^2 attributed to the variables. About half was attributed to demographics and small amounts to the other variables (Model 5: SIRE = .57, climate = .079, UVR = .003). Note, the variance importance metrics for the regression models were made available in the supplement.

To see if the geospatial variables (latitude, longitude, and elevation) were leading to underestimation of the effects of temperature and UVR we ran Model 5 without them. In Model 5b, the β for UVR was not significant (β = -.04); contrariwise, the β for temperature was significant, but again in the wrong direction (β = .11). Thus, the inclusion of the other geospatial variables was not likely to be the reason for the results we found.

A reader suggested that we use county-level general socioeconomic status, instead of test scores, as a measure of county-level "intelligence." The reader cited a conception of societal-level "intelligence" by sociologists Talcott

Table 5. County-level regression results for general socioeconomic status

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
	B	β	B	β	B	β	β
Intercept	.11***	.08***	.06***	.07***	.06***	.24	.10***
UVR	-.17***		-.03	.15***	.20***	(nonlinear)	.41***
% Black		-.49***	-.48***	-.45***	-.39***	-.41***	-.44***
% Asian		.21***	.26***	.27***	.24***	.23***	.24***
% Hispanic		-.15***	-.15***	-.13***	-.15***	-.11***	-.07***
% Amerindian		-.25***	-.25***	-.26***	-.24***	-.24***	-.25***
Avg_temp				.16**	.13	.10	-.01
Latitude				.40***	.32***	.41***	.32***
Longitude				.21***	.12***	.14***	.13***
Elevation				.14***	.07**	.05	.01
CA_lag					.23***	.22***	.21***
UVR * % Black							.05
UVR * % Asian							-.05***
UVR * % Hispanic							-.09***
UVR * % Amerindian							-.04
R2 adj.	0.038	0.376	0.403	0.432	0.470	0.479	0.489
N	3093	3122	3093	3062	3062	3062	3062

Note:
*Weighted by the square root of population size. Values in parentheses are standard errors. * <.01, ** < .005, *** <.001. Model 1: UVR; Model 2: SIRE groups; Model 3: UVR + SIRE groups; Model 4: Model 3 + average temperature & latitude, longitude, and elevation; Model 5: Model 4 + spatial lag; Model 6: Model 5 + spline of UVR; Model 7: Model 6 + UVR*SIRE interactions. The dependent, general socioeconomic status, is described in Section 2.1.2.*

Parsons and Gerald Platt [66] which aligns with this idea. These results are reported in Table 5. Since León et alia argue that UVR acts on cognitive ability partially through socioeconomics (e.g.,[21]), these results are germane to their models. As seen, using county-level general socioeconomic status instead of cognitive ability did not substantially change the interpretation regarding the effect of the climatic or other variables. In Model 5, UVR was significant but in the wrong direction, while temperature was not significant and also in the wrong direction. Latitude was positively associated with socioeconomic outcomes just as it was with cognitive ones (Table 4, Model 5).

3.2. County vs. State Results

In order to replicate the results from León [21] and León and Hassall [34], we aggregated county data to the state level and then refitted all the models. This result was placed in Table 6. In the initial model, UVR had a stronger effect on the state level (Model 1, β = -.51) than on the county-level (Model 1, β = -.33). In Model 5 with the spatial lag variable, the magnitude of the effect increased (β = -.82).

There seemed to be an aggregation effect wherein higher-level results based on a small dataset (*n* = 49) gave markedly different results than those based on a much larger set (*n* ~3,100) of lower-level units. This pattern of results can happen due to zonation effects; these are effects resulting from how spatial areas are divided [67], or simply from chance given the small sample size and large standard errors.

Table 6. State-level regression results for cognitive ability

	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**
	B	β	B	β	β	β	B
Intercept	.01	.01	.01	-0.2	-.02	-.09	.16
UVR	-.51***		-.42	-.80**	-.82**	(nonlinear)	.20
% Black		-.65***	-.49**	-.70***	-.68***	-.70***	-.77***
% Asian		.14	.02	.40**	.42**	.35	.32
% Hispanic		-.44***	-.06	-.18	-.19	-.09	-.06
% Amerindian		-.23	-.14	-.13	-.12	-.14	.06
Avg_temp				1.77**	1.83**	1.82**	.20
Latitude				1.11	1.07	1.43	.34
Longitude				.85***	.84***	.94***	.67**
Elevation				.90***	.92***	.80**	.22
CA_lag					.10	-.02	-.07
UVR* % Black							-.08
UVR* % Asian							-.26**
UVR* % Hispanic							-.11
UVR* % Amerindian							-.37
R2 adj.	0.315	0.376	0.657	0.438	0.65	0.637	0.742
N	49	49	49	49	49	49	49

Note:
*Weighted by the square root of population size. Values in parentheses are standard errors. * <.01, ** < .005, *** <.001. Alaska and Hawaii excluded, D.C. included. Model 1: UVR; Model 2: SIRE groups; Model 3: UVR + SIRE groups; Model 4: Model 3 + average temperature & latitude, longitude, and elevation; Model 5: Model 4 + spatial lag; Model 6: Model 5 + spline of UVR; Model 7: Model 6 + UVR*SIRE interactions.*

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One way to test the zonation hypothesis is to examine pseudo-states (i.e. counterfactual state border maps that could have existed) and refit the regression model in the new state-level dataset. We did this using a custom algorithm that began by randomly assigning 48 states one county each before looping over states at random, assigning them one random neighboring (shared borders) county if possible (not already assigned). The algorithm finished when it was no longer possible to assign any more counties to states (meaning that all were assigned). We created 1,000 pseudo-states in this way. We then fit the regression models of interest (models 1-3 from Table 2) to the data. Full summary statistics and more details can be found in the supplement.

Table 7. County-level regression results for cognitive ability decomposed by White, Black, Hispanic, and Asian Sire

SIRE: White				**SIRE: Black**		
	Model 1	**Model 2**	**Model 3**	**Model 1**	**Model 2**	**Model 3**
	B	β	β	β	B	β
Intercept	.18***	.31***	.17***	-.20***	-.15***	-.19***
UVR	-.02	.30***	.02	-.05	-.03	-.04
Avg_temp	.02	-.17	-.04	.05	.03	.06
Latitude		.27***	-.03		.08	-.03
Longitude		.22***	.01		.24***	.14***
Elevation		-.10*	-.03		.28***	.17***
CA_lag	.62***		.62***	.42***		.40***
R2 adj.	0.416	0.042	0.418	0.202	0.064	0.217
N	3079	3049	3049	2124	2095	2095
				•		
SIRE: Hispanic				**SIRE: Asian**		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
	B	β	β	β	B	β
Intercept	-.14***	-.16***	-.14***	.28***	.37***	.28***
UVR	-.12***	-.37***	-.21***	-.15***	-.05	-.09
Avg_temp	.16***	.28***	.13	.19***	-.21	-.06
Latitude		-.19***	-.17**		-.37***	-.23*
Longitude		.29***	.12***		.15***	.05
Elevation		.28***	.14***		-.17***	-.06
CA_lag	.45***		.35***	.43***		.39***
R2 adj.	0.306	0.242	0.333	0.211	0.102	0.224
N	2628	2600	2600	1464	1443	1443

Note:
*These are the county-level results by SIRE subgroups. Weighted by the square root of population size. Values in parentheses are standard errors. * <.01, ** < .005, *** <.001. Model 1: UVR + average temperature + spatial lag; Model 2: UVR + average temperature + latitude + longitude + elevation; Model 3: Model 2 + spatial lag.*

Results show that across pseudostates, UVR generally has the largest effect measured in partial R^2 (.12). UVR was largest in the comparison but 44% of the time demographics combined had the larger partial R^2. The results indicated that while zoning could influence results at the state level, it was unlikely to do so in the present case. Generally, there seemed to be an aggregation effect such that geoclimatic predictors had validity at the state but not county level. The possibility of such paradoxes was the rationale for Lynn et al.'s [11] call for authors to examine data at multiple levels as a robustness check.

3.3 Separate SIRE Regression Results

After failing to find a latitudinal cline in cognitive ability for African and Hispanic Americans, León and Hassall [34] analyzed cognitive scores for non-Hispanic Whites separately and reported a significant effect for this group. They speculated that African and Hispanic Americans were protected from the adverse effects of UVR by darker skin color. Following León and Hassall's [34] lead, we ran separate regressions for Whites, Asians, Hispanics, and Blacks. For these analyses, we used the SIRE-specific cognitive scores. Since the dependent variable was the SIRE-specific cognitive score we did not include SIRE percentages as covariates. Model 1 had UVR, temperature, and a spatial lag, while Model 3 added geospatial covariates. Model 2 was an alternative that repeated Model 3 without the spatial lag. Results were placed in Table 7.

Among Whites in Models 1 and 3 (spatial lag included), none of the geoclimatic variables were significant. Among Blacks, only longitude and elevation were significant (both positive). For Asians and Hispanics, temperature was either in the wrong direction (Model 1) or not significant (Model 3). For Hispanics, UVR was a significant predictor in the correct direction. However, this negative association was explicitly predicted to not exist by León and Hassall [34], who noted "the explanatory strength of UV radiation is shown not only by its ability to account empirically for [north-south cognitive decline among Whites] but also by its capacity to explain the absence of the north-south cognitive decline among non-White communities." For Asians, the effect of UVR was also in the correct direction and significant in Model 1, though it was not significant in Model 3. Similarly, latitude was not consistently in the predicted direction for any group. Overall, our results suggested either no notable role for the geoclimatic variables and UVR on cognitive ability, or, perhaps, very complex, heterogeneous causal paths of an unpredicted nature in the case of temperature, and overall insignificant effects in the case of UVR.

3.4 Gap Analysis

León [21] argued that the association between racial composition and cognitive ability was due to the higher distribution of Whites in states with low UVR. To evaluate this conjecture, we computed the average within-county Black/White, Hispanic/White, and Asian/White gaps, and then compared them to the national cognitive gaps in NAEP for the same years. To do this, county *d* values were weighted by the inverse of the standard error of the achievement gaps and then averaged. The SEDA did not include national averages, so we computed these ourselves using the NAEP explorer. Specifically, we computed effect sizes for each grade for the years 2009 to 2017. These years corresponded to those used in the SEDA database when mapping county achievement scores to state ones using NAEP math and reading results.

When computing effect sizes for the national differences, we used the White standard deviation, since this was the largest group and since sample sizes were not reported. In total there were 13 effect sizes (5 for Grade 4, 5 for Grade 8, and 3 for Grade 12) for each subject (math and reading). Following the method used in SEDA, we averaged across grades and years within subjects and then averaged across them. The average *d* values within counties and on the national level were given in Table 8 alongside the percentage of the national differences within counties. As seen, 64-73% of the gaps were within counties, supporting McDaniel's [4] proposition.

Table 8. Average within-county gaps versus national-level gaps

	Within-county *d*	National *d*	% (Within-county/national)
B/W	0.60	0.87	69%
H/W	0.44	0.69	64%
A/W	-0.16	-0.22	73%

Note:
The effects sizes are Cohen's ds. The within county ds are weighted by the inverse S.E. of the county-level ds.
Another way to approach the issue is to examine the predictors of the SIRE gaps.

Since ancestry groups are differentially adapted to climate ([28-29], [43]), if contemporaneous climatic factors affect cognitive ability and socioeconomic status they should have a differential effect across SIRE groups. For example, León and Hassall [34] conjectured that the greater melanin levels of Blacks and Hispanics "by absorbing

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and dissipating light, prevent the occurrence of radiation's cognitive effects among these populations at U.S. latitudes." If White but not Black and Hispanic Americans are affected by UVR, the magnitude of the Black/White and Hispanic/White differences should be smaller at higher UVR levels. Table 9 shows the correlation matrix for UVR, SIRE cognitive differences, SES differences, and county average cognitive ability and socioeconomic status. As seen in Table 9, there is no nontrivial negative association between higher UVR and the Black/White or Hispanic/White cognitive or SES gaps. The county-level cognitive gaps, instead, were better predicted by SIRE-specific socioeconomic status gaps and overall county-level socioeconomic status. Other geographic variables (average temperature, latitude) likewise showed trivial correlations with SIRE gap sizes.

Finally, we directly assessed whether SIRE composition was contributing to the differences between counties using the method detailed by Fuerst and Kirkegaard [69]. This method involved correlating the percentage of students of a SIRE group and difference scores across counties. These difference scores were the differences between the actual county average scores and what the county scores would have been in the absence of a specific SIRE group. Since the overall county scores were the weighted sum of the SIRE scores, it was readily determinable if a higher proportion of one group was leading to higher or lower cognitive ability scores, so long as one had both SIRE percentages and scores by SIRE groups. Since this method relied on within-county differences it was not confounded by unmeasured factors which varied between counties. The Pearson correlations for counties were: $r_{\text{Asian \%}} = .63$ ($N = 1,473$), $r_{\text{White \%}} = .25$ ($N = 3,102$), $r_{\text{Hispanic \%}} = -.87$ ($N = 2,637$), and $r_{\text{Black \%}} = -.94$ ($N = 2,125$). For school districts, which are nested within counties, the correlations were: $r_{\text{Asian \%}} = .87$ ($N = 4,683$), $r_{\text{White \%}} = .37$ ($N = 12,762$), $r_{\text{Hispanic \%}} = -.71$ ($N = 8,832$), and $r_{\text{Black \%}} = -.87$ ($N = 6,197$). Here, a positive correlation indicated that the

Table 9. Correlation matrix of group gaps and other variables

	CA	CA Black	CA Hisp	CA White	CA d bw	CA d hw	SES all	SES Black	SES Hisp	SES White	SES d bw	SES d hw	UV
CA	1.00	.65	.61	.69	.13	.15	.75	.42	.34	.40	-.24	-.04	-.37
CA Black	.67	1.00	.59	.40	-.46	-.09	.43	.55	.27	.21	-.53	-.11	-.17
CA Hisp	.60	.54	1.00	.35	-.16	-.48	.25	.24	.35	.08	-.25	-.32	-.16
CA White	.76	.47	.42	1.00	.63	.65	.60	.41	.33	.76	.00	.28	-.10
CA d bw	.17	-.46	-.09	.57	1.00	.71	.24	-.07	.08	.57	.46	.37	.02
CA d hw	.19	-.02	-.50	.57	.61	1.00	.36	.19	.02	.65	.20	.52	.01
SES	.73	.46	.24	.58	.22	.35	1.00	.65	.56	.73	-.33	-.06	-.20
SES Black	.43	.50	.24	.40	-.06	.18	.65	1.00	.55	.56	-.84	-.15	.12
SES Hisp	.28	.22	.28	.28	.09	.02	.50	.50	1.00	.50	-.35	-.69	.10
SES White	.37	.20	.10	.65	.49	.54	.73	.49	.46	1.00	-.06	.22	.06
SES d bw	-.27	-.45	-.22	-.07	.35	.13	-.36	-.87	-.31	-.05	1.00	.35	-.15
SES d hw	-.02	-.08	-.22	.20	.27	.39	-.06	-.16	-.72	.16	.31	1.00	-.11
UVR	-.33	-.25	-.17	-.10	.05	.01	-.19	-.02	.05	.08	-.02	-.05	1.00

Note:
CA = overall county cognitive ability, CA Black = Black county-level cognitive ability, CA hisp = Hispanic county-level cognitive ability, CA White = White county-level cognitive ability, SES = overall county SES, SES Black = Black county-level socioeconomic status, SES Hisp = Hispanic county-level socioeconomic status, SES White = White county-level socioeconomic status, CA d bw = county Black/White cognitive gap, CA d hw = county Hispanic/White cognitive gap, SES d bw = county Black/White SES gap, SES d hw = county Hispanic/White SES gap. Correlations above the diagonal are weighted by the square root of population size. N = 1981 to 3132 (Ns in notebook).

SIRE group's presence was raising the county or school district scores relative to what it would have been without that group. Thus, McDaniel's [4] conjecture was consistently supported.

4. Discussion

We analyzed a large dataset of U.S. counties to test whether UVR levels and other geoclimatic variables could account for geographic variation in cognitive ability. We found that although UVR, temperature, and latitude correlated with cognitive ability, these relationships were generally neither robust nor consistent. In contrast, variation in cognitive ability across U.S. counties were strongly and robustly related to variation in the demographic composition of the counties. While it has been found that low Vitamin D levels are associated with cognitive deficiencies on the individual level [31] there appears to be no such association on the regional level. Indeed, if UVR can be taken as an index of Vitamin D levels, then these results would suggest a slightly, though inconsistently so, negative association between Vitamin D levels and cognitive ability.

Results from analysis of county-level data conflicted with results from the state level reported in the literature. This suggests an aggregation effect or modifiable unit area problem (MUAP; [70]). We found that when we simulated random pseudo-states roughly similar to the actual ones to test for a MUAP this level discrepancy was often replicated (i.e., a variable which was unimportant when analyzed at the county level turned out to be important when analyzed at state level and vice versa).

We found that all variables showed substantial SAC. Some of this was also seen in model residuals. SAC in the residuals suggested either causal variables that themselves are spatially autocorrelated were omitted from the models or that the variables were measured with considerable error. As expected, the addition of a spatial lag variable removed the evidence for SAC in the residuals.

SAC in residuals is regarded as a problem because it can result in spurious associations and it can lead to overestimated precision of model estimates because the data points are not fully independent. Thus, in line with previous studies ([37-38]), we recommend that researchers employ spatial statistics in their regressions when using aggregated data. The supplement includes spatial lag variables computed for this study (for counties and states) which can be used by others.

Globally and within nations there is substantial and persistent geographic variation in cognitive ability (Lynn et al. [11]. While intelligence researchers generally attribute little variance (1-3%) to current climate and geography [12], geoclimatic models of human behavioral variation have resurged in interest (for a brief history of these models, see [15]). For example, 80 authors replied to Van Lange et al.'s [19] target article on the Climate, Aggression, and Self-control in Humans model. Moreover, there has been increased interest in light of possible effects of climate change (e.g., [16], [18]). Despite this, most research with cognitive ability as the criterion has used global or national samples where evolutionary history and geography are strongly confounded. Moreover, these analyses, by focusing on nations or states as units, limit analytic sample sizes and the ability to discriminate between predictors.

We addressed these issues by examining U.S. county differences (N = 3100), which allowed for multiple means of controlling for demographic confounding. The results did not provide consistent evidence for any geoclimatic model. It would be worthwhile repeating this analysis for other countries for which post-1500 migration waves may have attenuated associations between evolutionary history and geography (e.g., Australia, Canada, and Brazil). That said, geoclimatic variables could still be useful scientific tools for understanding geographic variation in cognitive ability. If they are not proxies for contemporaneous environmental factors, they could have had evolutionary impacts ([28], [43]) which might be evident in countries with mostly indigenous populations.

5. Conclusion

The present study is limited by several factors. First, while the sample size is large, the models used here are only cross-sectional. Although cognitive ability and demographic data have existed at the county level for multiple years (2009-2016), UVR levels do not change quickly and thus frustrate the use of a fixed effects (panel) design. Second, we reported data from only a single country. It is possible that relative wealth or some other characteristic of the U.S. obscure the putative geographical effects of the variables examined here. Further studies will need to be done for other countries to support or disconfirm this suggestion. Third, we did not have access to individual level data. It is possible that our county-level results are different from results discovered at the individual level and one cannot draw a definite conclusion that they are or are not (i.e., the ecological fallacy; [40]) with the present data or results.

An additional potential limitation is range restriction in the geoclimatic variables. The range of temperature and UVR in the U.S. is less than the level of variation across the globe. That said, the geoclimatic range in the U.S. is greater than in most other countries, including those for which associations have been reported. As such, if the

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range is too restricted for the U.S. then the variables may be of limited general use when it comes to intra-country associations. Moreover, the effects found were in directions inconsistent with typical hypotheses or were not consistently significant (e.g., Table 7), evincing no clear pattern to the geoclimatic results. For this reason we did not attempt to correct effects for range restriction relative to global UVR variance. Finally, it should be reiterated that the analyses conducted here were correlational. That said, as noted in the introduction, geoclimatic research is generally limited to correlational designs. Since previous research, showing an apparently robust relationship between geoclimatic variables and regional outcomes, has also been correlational, our conclusion-that there is no robust association-is relatively uncompromised.

In sum, large, geographically distributed differences in cognitive ability exist. These differences need to be accounted for. Several models have been proposed which have attempted to explain these differences in terms of contemporaneous geoclimatic ones. However, our present results agree with the majority opinion of intelligence researchers, that contemporaneous geoclimatic factors are not major determinants of variation in cognitive ability [12], at least for regions with geoclimatic variation similar to that in the U.S. Nonetheless, examining data in regions other than the U.S. would help to better evaluate these issues, as it may be that warmer climates or more intense UVR are needed to trigger the proposed physiological mechanisms through which these variables might affect cognitive ability.

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ARTICLE

Pollution Aspects Interconnections to Socio-economical impact of Natuf Springs-Palestine

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ABSTRACT

This study aims at determining the types of pollutants and their sources for the springs in the Natuf catchment/Palestine in addition to evaluating the socio-economic environmental impact on water utilization from residential people. Twelve spring water samples were collected for hydrochemical qualitative analyses of major and trace elements as well as microbiological analyses in the summer of 2017. Plotted spring water samples on the Piper Diagram indicated the water type of Mg-Ca-HCO3- and eleven samples could be classified as fresh water. Fifty questionnaires were distributed to the farmers and land owners in order to study the impact of socio-economic and environmental conditions for the spring water utilization. The study shows that 90% of local people are using the springs for agricultural purposes. The spring water chemical analysis indicates that they are free from industrial pollutants in regards that 84% of them are located away from the dumping sites. The study shows that respondents are not interested in rain water harvesting during winter season, because 44% of them have their own cisterns. The existence of the water network as well as the absence of the related authority role's contributes to the reduction of people's dependence on spring water. The results will be used for the qualitative aspects potentiality of the appropriated rainwater harvesting techniques to be installed in the area. It is recommended to establish a qualitative monitoring network in Natuf watershed as well as for the springs of the other catchments in the west Bank.

1. Introduction

The quality and quantity of spring water varies over time and space, and is influenced by natural and man-made factors, including climate, hydrogeology management practice and pollution. Access to drinking water in sufficient amounts and good quality is everyone's right [1]. Water is the key to life and human activity [2-4]. However, natural causes such as weathering and erosion of bedrocks, ore deposits, climate change and anthropogenic activities (agriculture, urbanization, and industries) adversely affect and limit the use of the groundwater for drinking and irrigational supply [5,6]. The degradation of water quality has various direct and indirect impacts on human health. In the West Bank, the domestic and agricultural water demand has increased in the last few decades in regards to

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the increase of population growth in the West Bank. The study area is the Natuf catchment, which recharges partly the Western Aquifer Basin (WAB) in the West Bank [7]. The scarcity of water, urban extension and the lack of interest in spring water resources are the main causes for the limited land use for agriculture [8]. Water pollution aspects are the main concern that helped in the preparation and implementation of the successful water management plan that may reduce pollution to the springs in the study area. The objective of the study is to determine the pollution aspects for the springs in the Natuf catchment and to study the socio-economic-environmental impact of spring water use for the inhabitants of the study area.

2. Materials and Methods

2.1 Study Area

The study area is Natuf drainage catchment, which is located in the western sides of Ramallah - Palestine. It is surrounded by the Quilt Catchment from the East, the Sarida Catchment from the North, the Salman and Soreq catchments from the South and the Coastal Plain from the West (Figure 1). The Natuf catchment is composed of thick layered limestone, dolomite, chalk and marl [7]. The majority of springs are located in the central part of the study area, where the Yatta formation exists as aquiclude (with interlayered marl and marl limestone). The springs are emerging from a perched aquifer of karstified nature composed of dolomite and limestone outcroppings belonging to formations of the Albian and Turonian age.

Ahmed [10] studied the impact of wastewater as a main source of pollution that originate from the Israeli Ara'el settlement on the quality of spring water in Sarida Wadi and concluded that some parameter's concentrations exceed the standard limits for drinking water in most tested samples, such as BOD_5 and TSS, while other parameters showed concentrations complying with standards and guidelines like Ca^{2+}, HCO_3^- and Cl^-, for NO_3^-. Bader [11] studied the impact of cesspits on polluting springs water and some additional types of pollutants in the Natuf catchment (Ramallah area) and concluded that there are two main sources of pollution in the study area; cesspits and random dumping sites. Rainwater harvesting has become one of the alternatives that people resorted to in order to compensate for the shortage of water supply by the local internal water networks in many areas in the West Bank [12]. Wastewater, resulting from houses, hospitals and factories is considered to be the most dangerous pollutant that threatens the environment in general, and water resources in particular [13]. The Palestinian Central Bureau of Statics annual report in 2009 that 84% of industrial facilities and buildings are not connected to the sewer system network, and rather depend on cesspits and random disposal through seasonal Wadis, which causes harmful pollution to the environment. Shalash and Ghanem [9] studied the chemical, physical and biological parameters for spring water in the Natuf catchment (Ramallah area) and they found that the majority of springs in the Natuf catchment area are suitable for household and farming activities, which means that springs are free from hazardous pollutants.

2.2 Methodology

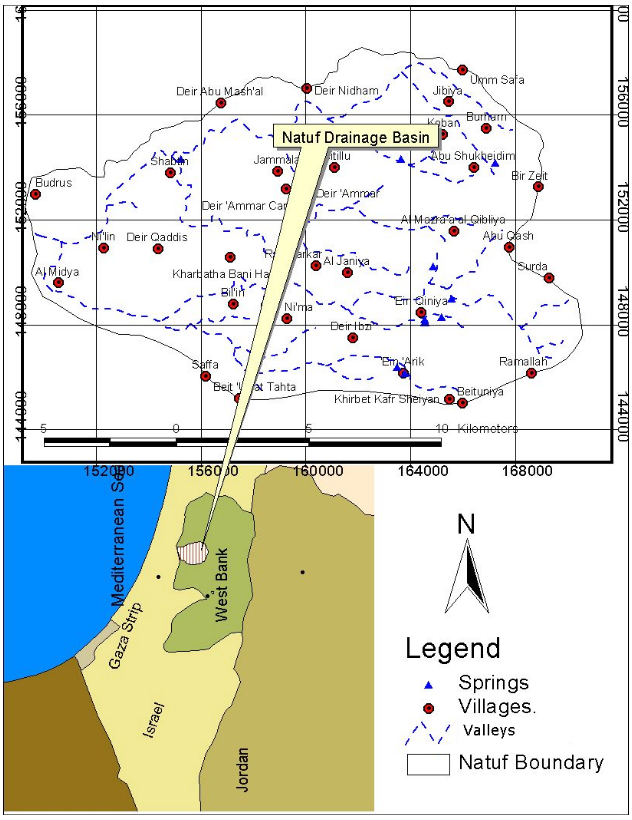

Figure 1. Natuf catchment study area [9]

Twelve spring samples were taken using 1 L polyethylene bottles. Physical parameters including temperature (T), electric conductivity (EC), dissolved oxygen (DO), pH and total dissolved solids (TDS) were measured onsite using a Hanna Field Multimode Meter. Hydrochemical parameter analysis of Na^+, K^+, Mg^{2+} and Ca^{2+} as well as the trace elements Ag, Al, B, Ba, Bi, Cd, Co, Cr, Cu, Fe, Pb, Li, Mn, Mo, Ni, Ti and Zn were carried out at Al-Quds University Labs using ICP-MS, while the analysis of HCO_3^-, NO_3^-, Cl^-, SO_4^{2-} was undertaken at the Water Lab of Birzeit University. A volume of 100 ml of each collected sample was acidified with Avistar concentrated 69% nitric acid (14.4 M HNO_3) and stored at 4 ºC until analysis.

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100 ml sterile glass bottles were used for collecting samples for microbiological tests of total coliform (T.C) and fecal coliform (F.C). Fifty questionnaires were distributed randomly to the landowners and the farmers in order to understand the socio-economic and environmental conditions in the study area. The questionnaire consisted of four main parties; the first one is personal information such as age, educational level, sex and job. The second part is related to the frequency of use of springs water and the dangers that affect them. The third part is about the effects of farm land reclamation on the quality of the springs through using fertilizers and pesticides, and the last part is the rainfall harvesting and spring water management. Data of questionnaires were analyzed using SPSS software.

2.3 Results and Discussions

(1) Physical and hydrochemical characteristics of springs

Results of physical parameters of the spring water samples are summarized in Table 1. According to TDS, EC and HCO_3^- results, water can generally be classified as fresh water which is suitable for all purposes (household and farming). The values of TDS and EC for all water samples are ranging between 294-642 mg/L and 650-1120 µS/cm, respectively. The maximum value of TDS and EC was recorded at Abu Danfora spring with 624 mg/L and 1120 µS/cm respectively. The possible causes of this are mixing with treated effluent that discharges from the Al-Tirah wastewater treatment plant, and the proximity the of springs to agricultural areas. The relationship between TDS and EC of spring water of the study area is strong and TDS versus EC values showed that the value of the linear correction coefficient R^2 is close to the one shown in Figure 2.

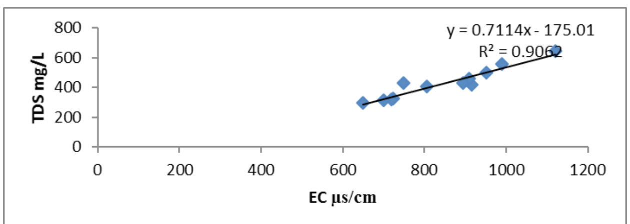

Figure 2. Relationship between TDS and EC for springs water in Natuf catchment area

The pH values for all samples were within the normal range 6.8-7.1 with a mean of 6.9, which reveals that all inorganic carbon exists as bicarbonate (HCO_3^-). The measured temperature of all springs, which is considered as a sensitive indicator for monitoring of groundwater, ranges between 21.6-24.6 ºC with an average of 22.9 ºC.

Table 1. Statistical values of physical parameters for spring water samples in the study area

Spring's Name	TDS mg\L	EC µS\cm	DO mg\L	T Cº	PH
Wad Reya	501	951	6.8	21.6	6.95
Al-zarka, Beitillu	420	915	5.7	24.6	6.89
Ein Arik Al-tehta	405	805	7,05	22.6	6.92
Ein- Arik Al-Fuqa	294	650	7.6	22.2	7.05
Ein Ayoub	460	910	6.4	21.9	6.99
Al-zarka, Abud	430	748	5.9	22.6	7.08
Al-balad	431	895	7.6	24.3	6.81
Al-qus	320	720	7	24	6.93
Popin	326	723	6.5	22	7.01
Wad Al-limon	560	990	6.2	22.7	6.77
Om Al-roman	315	700	5.25	23.2	6.84
Abu Danfora	642	1120	5.30	24	6.79

Results of the cations and anions hydrochemical parameters are listed in Table 2. Ca^{2+} concentrations of spring water samples varies from 5.29 mg/L in the Al-qus spring to 19 mg/L in the Abu Danfora spring with a mean of 9.7 mg/L. The higher concentration of Ca^{+2} in Abu Danfora spring likely relates to a longer water contact time (residence time) with minerals, and a continuous weathering process of soil and bed rocks. Mg^{2+}, analysis showed that there is no significant difference among Mg^{2+}concentrations between spring water samples. Results of K^+ for all studied samples showed that there is no source (anthropogenic) that may increase concentrations of K^+ since concentrations were below the limited value of the WHO guidelines. The concentration of Na^+ for all water samples ranges between 10 - 31 mg/L with the exception of Abu Danfora spring, which is recorded as the highest value of 76 mg/L (Figure 3). This high value is due to the mixing process of treated effluent that discharges from the nearby Alterih wastewater treatment plant, in addition to the farming activities and use of fertilizers around the spring.

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Table 2. Analyzed hydrochemical parameters of the spring water samples (in mg/L) and their correlated WHO standards.

Spring's Name	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-
Wad Reya	7.5	21.2	14.5	0.5	177	33.8	23	7.1
Al-zarka, Beitillu	11.9	24.2	19.3	1.5	182	33.1	23.8	6.5
Ein Arik Al-tehta	11.8	16.9	31.8	5.2	201	35.2	16.8	6.1
Ein- Arik Al-Fuqa	5.4	15.2	12.8	1.2	183	34.5	23.7	8.7
Ein Ayoub	9.2	19.7	26.1	1.4	166	36.2	18.5	7.8
Al-zarka, Abud	5.3	12.4	14.3	0.6	193	38.3	26.5	6.9
Al-balad	11. 7	25.6	23.3	0.8	188	45.2	20.8	8.5
Al-qus	5.3	17.6	11.6	0.6	168	36.7	18.7	8.1
Popin	9.6	16.5	12.1	0.97	178	40.2	29.8	8.2
Wad Al-limon	10.7	11.3	12.5	0.49	192	49.8	21.2	7.9
Om Al-roman	9.4	17.2	9.9	1.16	209	33.2	27.3	6.6
Abu Danfora	19	15.3	76.4	2.72	205	39.4	23.9	6.9
WHO Standard	75	30	200	10	100	250	150	45

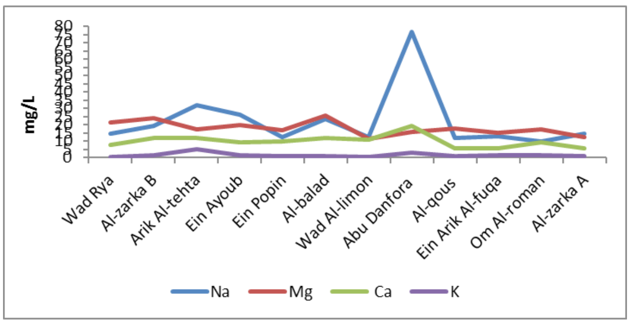

Figure 3. Concentrations of cations for spring water in the study area

Concentrations of NO_3^- in groundwater can generally be affected by cesspits, farming activities (fertilizers), septic tanks and animal manure. Concentrations of NO_3^- for all water samples range between 6.1-8.7mg/L which is well below the WHO standard limit of 50 mg/L (Figure 4).

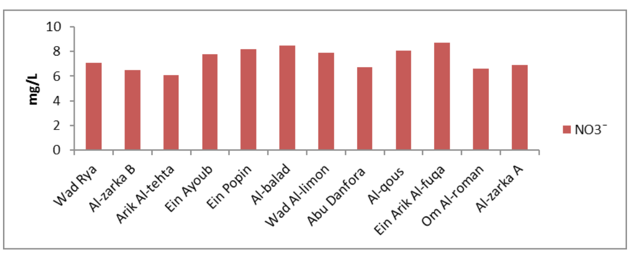

Figure 4. Nitrate concentrations for spring water samples in the study area

The acceptable level of bicarbonate in drinking water should be less than 500mg/L [14]. The measured values of HCO_3^- for all samples were less than the limited value of the WHO and range between 166-209 mg/L, which proves the suitability of using these springs for drinking purposes. The highest concentration could be recorded in the dry season due to the longer residence time of water with dolomite and limestone.

Based on the Palestinian standards for drinking purposes, the standard level of Cl^- is 250 mg/l and the concentration of SO_4^{2-} is up to 250mg/L. The measured concentrations of Cl^- range from a maximum value of 49.8 mg/L at Wad Al-limon spring to a minimum value of 33.1 mg/L at Al-zarka spring (Beitllu village). All SO_4^{-2} concentrations are below WHO standards.

Generally, the major ions of the analyzed spring water hydrochemical parameters are within the WHO standard methods for drinking purposes, with the exception of Bicarbonate parameter (Table 2). The high concentration of bicarbonate in the analyzed spring water samples is due to the carbonate nature of the aquifer feeding springs in its rock-water interaction processes.

The presence of TOC was recorded only in the springs of Ein Arik Al-tehta and Al-zarka Bietillu, while the rest of samples were free of it. The presence of TOC could be attributed to wastewater contamination, which is verified by the existence of fecal coliform in samples from the same location.

The trace elements concentrations of Ag, Al, B, Ba, Bi, Cd, Co, Cr, Cu, Fe, Pb, Li, Mn, Mo, Ni, Ti and Zn are within the limits of the WHO guideline with the exception of Zn which recorded highest in the springs of Abu Danfora , Al-qus and Al-zarka Beitillu (Figure 5).

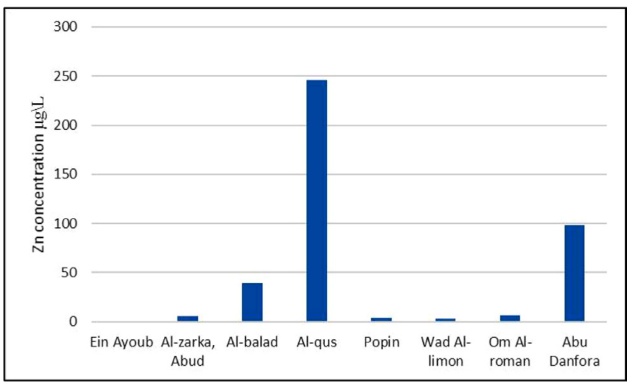

Figure 5. Concentrations of Zn in spring water samples in the study area

Microbiological analysis of water samples showed that the springs of Wad Reya, Al-zarka in both Beitillu and Abud , Ein Arik Al-tehta and Al-fuqa , Popin and Al-bald are contaminated with fecal coliform bacteria, which

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indicates the presence of pathogenic micro-organisms in these springs. The highest concentration of fecal bacteria was recorded at Ein Arik Al-tehta with 42 {CFU/100ml} and the lowest one is recorded in Al-zarka Beitillu with 7{CFU/100ml } (Figure 6).

Ghanem et al. [15] mapped groundwater quality indicators in Natuf surface water basin and integrate them in the spatial distribution of the surrounding environment. Results were used in a regional water-quality trend assessment and the spring water was found to be polluted in the springs located inside the populated areas. Relationships between different hydrochemical parameters reflect the carbonate nature of the western aquifers. Spring water in the study area is found to be circum neutral to slightly alkaline with average pH ranging from 6.4 to 8.3 and the EC values ranging from 410 to 1307 µS/cm. The average concentrations of anions and cations in all water samples are within WHO standards, with the exception of calcium in some samples. New measurements were uploaded along with historical water quality data to the online mapping and data management system myObservatory, where they could be added to, accessed, and analyzed by multiple users including decision-makers in the study area. Twelve physical and hydrochemical parameters and seven trace elements for water samples during the dry 2003 to wet 2005 seasons, were tested by conventional chemical and instrumental methods from 12 springs and one shallow dug groundwater well in Natuf drainage basin in the western hills of Ramallah district in the West Bank [9]. The results show variations in chemical composition between dry and wet seasons and from one spring to another. Springs near populated areas and near agricultural activities show high values of EC, SSP, SAR and TH.

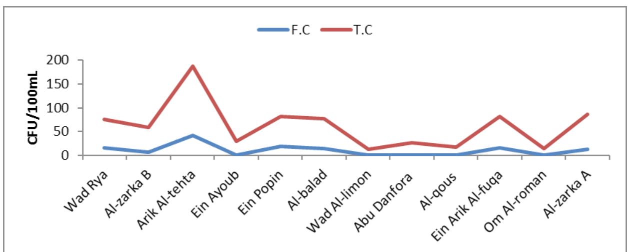

Figure 6. Concentrations of F.C and T.C bacteria for spring water samples in the study area

(2) Socio-economic analyses

Fifty questionnaires were distributed to farmers and land owners who mostly utilize spring water in the Natuf catchment area. The fifty farmers respondents were chosen only for those who are currently using the water springs for irrigation in regards to the majority of farmers were immigrated from agricultural activities and moved to trade or in building sector in Israel. The questionnaire aims at showing the social, economic and political effects of exploiting the spring water in the study area on its residents' life, and the obstacles that limit their utilization of the spring water, whether they are environmental or political obstacles.

(3) Spring utilizations

Springs are one of the most important water resources in the occupied territories, especially in the Natuf catchment which contains 78 springs in Beitillu village only. The study shows that spring water in the study area is used in farming and for drinking purposes, with 89% from the questioned people using it for farming, 9% of them using it as drinking water and 2% of them using it for other purposes such as constructions. Supposedly, the concerned authorities such as the Palestinian Water Authority (PWA) and Authority of Quality Environmental Assurance and the Ministry of Archeology and Tourism should show interest in the quality and the rehabilitation of the spring water as they are part of national security. However, in the study area, it is found by analysis of the received data from the questioned people that 79.8% of them believe that the authorities do not care about these springs, while 20.8% of them believe that these authorities take care of springs from time to time.

(4) Springs and pollution

Wastewater is considered as one of the pollution sources that threats the groundwater quality if it disposed raw or not fully treated into the receiving environment. The major urban areas in the study area extend geographically over the high parts of Ramallah, and these high parts are the main recharge area to the Natuf basin. The inadequate disposal of wastewater, especially over the highly permeable areas of the karstic, limestone, will definitely endanger the quality of groundwater. In the study area, the majority of villages are missing sewer systems and people dispose of their wastewater through cesspits or in open areas. Therefore, people were asked whether their cesspits are close to the springs. The answer is 36.7% of springs are located close to cesspits, while 63.3% of springs are not close to them. Even though the vast majority of springs are located far away from the cesspits, the population in the study area disposes of the cesspit's waters by withdrawing it by tanks and then discharging it in the neighboring Wadis, which are close to springs like Ein Qinia and Abud village, which will contribute to groundwater contamination (Figure 7).

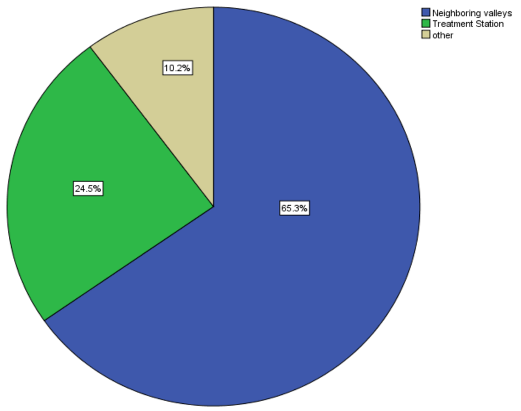

Figure 7. The places where people dispose cesspits contents in the study area

Dumpsites are another source of groundwater pollution and there are no sanitary landfills in the study area, so people tend to dispose their solid wastes randomly near roads, farming lands or close to water resources. People were asked whether there are dumpsites located close to the springs, and 84% responded that springs are not close, while 16% reported dumpsites located near to them, which indicates a potential role of dumpsites in polluting the springs of the study area.

(5) Farming in the study area

Nowadays, the agriculture in the Natuf area has retreated sharply for many reasons related to over population, urban expansion, occupation policy and measures that led to decreasing the importance of agricultural production and farming lands. In the study area, 77.1% of the questioned people cultivated their lands, while 22.9% did not. The results of the analysis to the questionnaires show that 40% of lands are planted with vegetables such as lettuce, parsley, cauliflower, aubergine, while 28.6% are planted with field crops, and 31.4% of them with olives and fruit trees (Figure 8).

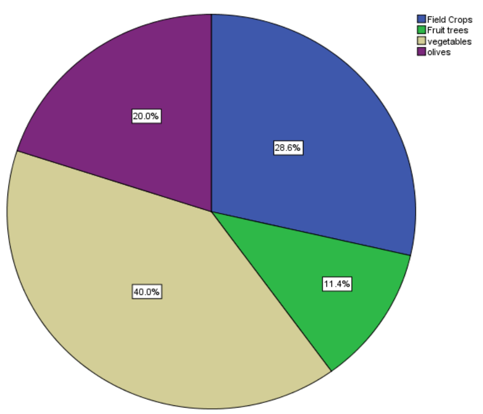

Figure 8. Types of crops that people farm in their lands in the study area

Irrigation methods vary in the study area, as the farmers use three available methods. The study shows that 50% of farmers use plastic pipes for drip-irrigation , while 31% of them directly irrigate their crops as they are close to the springs, and the least used methods is channel-irrigation, which is used especially in the Ein Qinia village because the farm lands are plain terrains and there is abundance of water in this area. Fifty five percent of farms using industrial chemical fertilizers and pesticides and their amounts ranging between 1-5 kg; while 33.3% using 5-10 kg, and 3.7% using 10-20 kg. The percentage of farmers who use more than 20 kg is 7.4%. This reveals the lack of farmer's awareness toward the use of industrial fertilizers and pesticides, and how these pesticides are affecting the environment and water resources in the area. These fertilizers and pesticides may play a role in contaminating soil and groundwater if they are used excessively. Although the majority of the questioned people practice farming in the study area, farming is not considered as a main career for them, which indicates that farming is not a primary source of income for the families in the area. It is shown that for 75.5% of the questioned people, farming is not the primary source of their income, while 24.5% of them consider it as primary income source. Sixty five percent of questioned people confirmed that their aim of farming in the study area are related to home uses and food consumption, while 34.7% of them farm to sell on the market.

(6) Rainfall harvesting in the study area

The Palestinian population growth in the West Bank has limited water resources which pushed them to look for alternative water resources (Abu-Madi et.al 2008). One of these alternatives is rainwater harvesting. Rainwater harvesting means the capture, diversion and storage of rainfall water for multi-purposes including landscape irrigation, drinking and domestic uses. In the Natuf catchment, it is clear that the questioned people show little interest in rainwater harvesting, with 44.9% of them collecting rainwater in the winter season as an additional water resource to springs in the area, while 55.1% of them do not care about rainwater harvesting, as they feel there is enough water resources availability. Rainfall water is affected by different factors including climatic condition, surrounding environment, storage time of water and roof catchment materials. In the study area, the questioned people show some degree of awareness of the health risks that may be caused by rainwater if it is collected or consumed without cleaning the roof surfaces in the area. The study showed that 64.7% of questioned people clean roof surfaces before rainwater harvesting, whereas 35.3% do not.

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(7) Socio-economic and water quality relation for springs in the study area

Table 3. Chi-Square Test in the study area

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	4.757a	1	.029		
Continuity Correctionb	3.184	1	.074		
Likelihood Ratio	7.358	1	.007		
Fisher's Exact Test				.044	.027
Linear-by-Linear Association	4.658	1	.031		
N of Valid Cases	48				

a. 1 cells (25.0%) have expected count less than 5. The minimum expected count is 2.75.

b. Computed only for a 2x2 table

Sixty three percent of the questioned people in the study area asserted that the majority of springs are located far away from cesspits. Lab analyses showed that seven water samples out of twelve were contaminated with fecal coliform bacteria, which reveals the impact of human activities on spring water quality. There was a good noticeable match between the results of the distributed questionnaire analysis and parameters lab tests analysis of the spring samples of being water analyses free from industrial pollutants and the answered questionnaire respondents stated that 84% of studied spring are located far away from randomly dump sites and industrial activities. Despite the fact that the majority of farmers are using different amounts of chemical fertilizers ranging between 5-20 kg. However, there is no effect of these fertilizers on the quality of spring water, especially as the chemical analysis of water samples showed that the measurements of TDS, EC, cations and anions were within the WHO guidelines and Palestinian standards for drinking water. The questionnaire analysis showed that the higher percentage of springs in the study area are used for agricultural purposes and not for drinking. This can be attributed to the fact that the presence of internal water network lead to the easy access to water. There is a relation between lack of interest of concerned authorities toward springs and deterioration of the springs water quality, but it is not statistically significant at $\alpha \leq 0.05$. The questionnaire analysis showed that 64.7% of the questioned people who are cleaning their roof surfaces before rainwater harvesting reflects a strong awareness degree of water quality matters. Based on Chi-Square testing in SPSS, it is shown that there is a relationship between farming and source of income with a statistically significant at $\alpha \leq 0.05$ (Table 3).

3. Conclusions

Assessment of groundwater quality is essential to ensure its suitability for drinking and agricultural purposes. This study was carried out to assess the overall spring water quality and identify major variables affecting the groundwater quality in the Natuf catchment of West Bank and interlinking them with the socio-economic aspects and environmental behavior. Groundwater quality indicators were determined and integrated with spatial information about the surrounding environment. Twelve spring water samples were collected and analyzed for hydrochemical parameters (pH, TDS, EC, DO, Ca^{2+} , Mg^{2+} , K^{+} ,Na^{+} , HCO_3^- ,Cl^- , SO_4^{2-} , NO_3^- , TOC) as well as microbiological parameters (F.C and T.C) to ensure the suitability of water for household and farming activists. Results indicated that the spring waters are good enough for farming and human consumption. Seven water samples out of 12 are contaminated with fecal bacteria, which reveals to the anthropogenic impact on water quality. Trace elements for all water samples are within the WHO guidelines except Zn^{2+}, which recorded as the highest concentration of 5 mg/L. The presence of TOC was above the detection limit in two of the springs located inside the populated communities and this can be attributed to the presence of wastewater. The study shows that agriculture is not a basic source of income, but rather used for domestic benefits. The study also shows that the existence of Israeli settlements near the agricultural lands and springs have an indirect impact on spring water quality. Relationships between different hydrochemical parameters reflect the carbonate nature of the aquifers. Hydrochemical evaluations show that most springs in the study area are of water type (Ca-Mg-HCO_3). The presence of coliform bacteria and elevated concentrations of trace elements point to human impacts on water quality, and indicate the need for groundwater protection efforts in the study area. A qualitative monitoring system is recommended for the planners of the water and environmental authorities to be installed in the catchment in order to protect its water resources. Water qualitative modeling studies are recommended for monitoring pollution aspects for better water resources management integration.

Conflict of Interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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ARTICLE

An Analysis of Natural Factors Affecting the Dispersal and Establishment of Iron Age III (800-550 B.C) Settlements in the Western Zayandeh-Rud River Basin (West and Northwest of Isfahan)

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ABSTRACT

Humans are always effect to their surroundings, which makes it possible to create habitable environments and create habitat patterns that fit the surrounding environment. The interaction between human being and environment either in the form of human effect on the environment or the environment effect on the human, cannot be considered out of the environment. According to this approach in archaeology, environmental factors have an important role in assessing settlements in each period. In addition to the recognition of the degree of environmental impact, this approach makes the degree of adaptation of the habitats with the dominant environmental conditions possible. As geospatial tools become more powerful, GIS archaeology has evolved as well, making it possible to visualize ancient settlements and analyze changes in the use of space over time. By incorporating historic map data, physical details of an area's landscape and known information about past inhabitants, archaeologists can accurately predict the positions of sites with cultural, historical relevance. In this research Iron Age III (800-550 B.C)sites in the west and northwest of Isfahan were studied via GIS. The area studied is one of the most important but unknown areas of archaeological research due to its location in the center of the Iranian plateau and a link between the north-west and the south-west of the country. The environmental characteristics of the studied area have attracted the attention of humans since ancient times. Therefore, it was considered necessary to conduct archaeological excavations. To achieve this goal, the area was first studied archaeologically. As a result of this survey, approximately 50 ancient sites were identified which included the statistical population used for analysis. The effect of environmental variables including altitude, slope (percentage and direction), climate, geological structure, distances and proximity to water resources, land use and proximity to communication paths on the distribution of settlements in the study area was investigated. Through analytical-descriptive method, the factors affecting the formation and distribution of the establishment patterns of the period in question were examind. After analyzing the information and maps, the results indicated that among all the factors, three environmental factors were the most important in the formation of ancient settlements of the Iron Age III era in the west and northwest of Isfahan: factors relating to water resources, proximity to communication paths, and slope percentage and direction.

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1. Introduction

Geographical Information Systems has moved from the domain of the computer specialist into the wider archaeological community, providing it with an exciting new research method[1]. In fields where map-based data collection, data handling and service are in use, it is indispensable to use this modern solution. In addition to conventional technical applications, GIS became accepted in other disciplines too. Disciplines in the field of humanities are not exceptions to this concept[2]. For decades, GIS has been an integral part of archaeological practice and its many advantages and uses in visualizing and managing archaeological data have been discussed as well as examined from a critical and theoretical perspective [3]. Since the early 1990s one area of computer usage in archaeology, the use of Geographic Information Systems (GIS), has grown exponentially reflecting the importance of working with spatial data and spatial analyses of various kinds. Although this post-dates much of the theoretical debate taking place during the decades from the 1960s to 1980s, the use of GIS rekindled aspects of those debates albeit within a spatial context and will be used here to illustrate some of the tensions that still exist between archaeological computing and theory[4].

GIS (Geographic Information System) is a highly important tool aiding in archaeological field studies in understanding the relationship between ancient sites and the environment as well as natural resources, and in defining interregional cultural boundaries. In the late 1960s, the analysis of ancient settlements became a key component of archaeological research's extensive questions regarding human adaptation to environmental diversity in a landscape[5]. Considering all the theoretical discussions concerning the use of the GIS system from 1960 to 1980, Luke emphasized that GIS was the most helpful tool in analyzing spatial information [6]. From the late 1990s onward, archaeologists have sought to make greater use of GIS in their research ti provide an overview of the distance between archaeological sites with the aid of data and environmental variables [7]. This points to the importance of applying new approaches and technics in archaeology and suggests the need to apply and develop such techniques as a central part of any modern archaeological investigation. Concern for these questions and with the overall potential that information systems provide to capture, represent, analyze, and model archaeological information implies the need for a new interdisciplinary focus, archaeological information Science. For such a focus to prosper, archaeologists need to develop additional skills that go beyond mere technical ones [8].

Archaeology not only reveals the past, but as a fundamental discipline in the humanities also plays a role in sustainability studies. Natural factors in creating and establishing settlements, physical-spatial and communication development act in different ways and in different places their positive aspects are highlighted while their negative effects are limited [9]. Environmental capabilities (natural and human) provide the basis for the establishment of human settlements in geographical spaces. In fact, the spatial structure of each place is the manifestation of the interaction between human society and its physical environment [10]. One of the requirements for examining the relationship between settlements in archeology and the environment is the coordination between the two parts. Understanding these conditions helps to know the strengths and limitations. Geography helps to achieve a perception of the interconnection between nature and man in geographic space; hence, "archaeologists and geography today share much in common" [11]. Human endeavor to change the environment has been made through knowledge and adaptation to the environment, and this is a great effort that has led humans to dominate the environment and formulate civilizations [12] . Establishment and emergence of a city are subject to environmental conditions and geographic location to a greater degree than any other factor [13]. The pattern of establishment which is in fact a way of adapting man to the vision that they live in inevitably requires the identification of the environmental factors which are considered influential factor [14]. Archaeologists interpret the settlement patterns of a region by collecting data from exploration and other techniques using social and environmental perspectives [15]. The establishment of human societies has always been in the pursuit of natural resources and the natural environment. Choosing the right place to settle is often influenced by a variety of factors such as nature, business and economic incentives. Natural factors take into account topography, water resources, climate, remoteness and proximity to communication pathways in addition to other factors. These natural factors, in the form of a geographic space, with the activities and manipulations of the environment by humans create a cultural model that is somewhat recognizable in archeology. Sometimes the environmental conditions provide a suitable framework for human habitation such as appropriate heights, slope percentages and directions, water resources, land use, and geological structures.

The use of GIS, as a valuable aid in understanding geographic information, can be extremely helpful in storing and analyzing information and preparing maps. Archaeological studies, on the one hand, seek to identify archaeological sites and, on the other hand, aim to iden-

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tify the relationship between archaeological sites and the environment as well as geography of each region. GIS provides data on altitudes, geology, access to water resources, land gradient surveillance, and more; therefore, it is highly effective in understanding the human relationship with the environment. Accordingly, it can be used to help archaeologists in the analysis of archaeological sites and relationship with the environment. The type of information provided in GIS to the archaeologist in the study of archaeological sites demonstrates that the formation of an archaeological site is not based on a random distribution pattern, and humans are modeled based on the conditions of their environment and thus chose their place of residence according to shape of the land, access to water resources, land slope, and land use. Analysis of this information helps archeology to determine the type of environmental use by humans. The result of this overlap of GIS and archaeological information contributes to assessment of archaeological sites using a topographic indicator. Hence the GIS information system assists archaeologists in analyzing spatial patterns and examines an archaeological site in terms of components such as altitude, slope percentage, geology, water resources, and communication routes. The connection between ancient sites and geographical data is finally presented as a map.

From the archaeological point of view, Isfahan Province is not well-known in relation to peripheral areas such as Fars and Khuzestan Provinces. From the prehistoric to the historical period, other than a few studies that have been undertaken in recent years which have led to a little understanding of this era, not much else is known. However, the midwest and north-west of the province due to the presence of high mountains, middle-mountain valleys and plains and nomadic settlements have been of interest since the distant past. Furthermore, due to its location between the western, south-west and central plateaues, it is an intermediary for cultural exchange between mountainous areas and plains. Therefore, recognition of the pattern of settlement and the effect of natural factors on the distribution of the sites of this era were taken into consideration. In the study of these settlements and their distribution, the variables that were considered from a geographical perspective were height, land use, remoteness and proximity to communication paths and water resources. In this research, using maps , the layout of Iron Age III sites identified in the West and North-West areas of Isfahan Province, which is a very important but unknown region, was investigated and analyzed. This research aims to answer the question of whether the formation and pattern of dispersion of settlements in the studied region were influenced by the mentioned conditions. In the studied area, it appears that environmental factors provide the conditions for habitation, although they are different in terms of impact. For this reason, factors such as slope, altitude, climate, percentage and direction of slope, geological structure, water resources and distances, and proximity to communication routes were considered to study the effect of natural factors on the distribution of Iron Age III settlements. In order to determine the effectiveness of the above factors, it was necessary to use GIS to determine the distribution of sites in relation to these factors. Analysis of the patterns of establishment elevates our knowledge of the cultural landscape of the region; it appears that in the studied area, environmental factors provide the necessary conditions for establishing settlements but they differ in their degree of impact .

2. Iron Age III Archeology in Iran

The transitional period between the Bronze Age and the Iron Age in Iran and the conditions at the beginning of the Iron Age is one of the most widely discussed subjects in Iranian archaeology and there is still no real consensus between archaeologists and historians. Iron Age is one of the most revolutionary periods in the history and civilization of Iran and neighboring countries. In Iran the term Iron Age is employed to identify a cultural change that occurred centuries earlier than the time accorded its use elsewhere in the Near East, and not to acknowledge the introduction of a new metal technology. Iron artifacts, in fact, were unknown in Iran until the 9th century BC. The Iron Age in Iran occupies a relatively short time span in archaeological terms, Iron I: 1250-1050 B.C, Iron II: 1050-800 B.C, Iron III 800-550 B.C. The term "Iron Age III" entered the Iranian archaeological literature with the studies of Dyson and Young at the Hasanlu site. This period covers the historical period of 800-550 B.C. Characteristic of the Iron III period in western Iran (known mostly from surveys) is the presence of many local ceramic assemblages consisting of both plain and painted wares, indicating a variety of regional developments, perhaps indicating discrete polities. The studies of this historical period became more coherent by explorations of the Silk region, Hasanlu [16], Nosh-I-Jan [17], Godin [18] and Baba Jan sites [19]. In the Iranian chronological calendar, it is associated with the presence of the Medes in the region and the formation of the Medes from approximately 800 to 550 BC and before the Achaemenid Kingdom. In addition to the extension of the Medes territory to the central plateau, in Greek sources, such as Herodotus, refer to the Parthians as the second Median tribe, which some researchers have regarded as the geographical location of present-day Isfahan.

3. Geolocation of the Study Area

The study area according to the distribution of Iron Age III sites includes several cities with northwest-southeast extensions, the northwest end of which is the newly isolated city of Boeing and Miyandasht with a geographical position of 50 degrees, 9 minutes and 54 seconds east longitude, and 33 degrees, 4 minutes and 25 seconds north latitude while the southern end of the city of Isfahan has a geographical position of 51 degrees, 40 minutes and 6 seconds east longitude and 32 degrees, 39 minutes and 15 seconds north latitude. The cities of Boein and Miyandasht, Dardan, Fereydoun-Shahr, Chadegan, Tiran and Karan and north of Isfahan are the areas of interest in this research. Geographically, this area is bordered by Khansar to the north, Khorramabad and Chahar Mahal and Bakhtiari to the west, Naein and Ardestan to the east and Lenjan, Mobarakeh, Shahreza and Chaharmahal and Bakhtiari provinces to the south. (Figure 1)

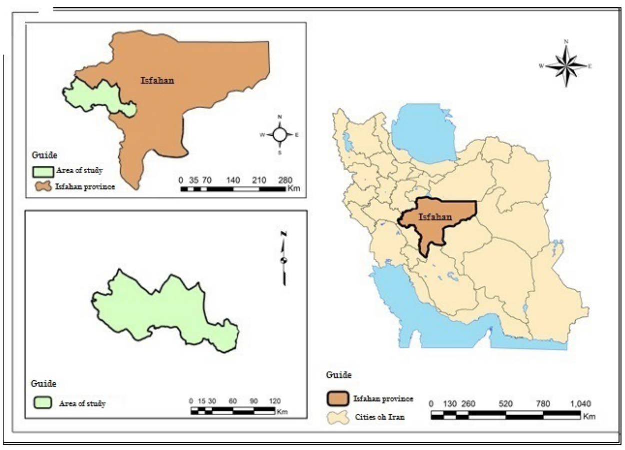

Figure 1. Map showing the area of study

Source: Field Survey (2018)

This area has two very different geographical landscapes. One of the most prominent features of this area is the existence of heights above 3000 meters and open plains with a height of 1860 meters next to each other. The north-west and west of the area has lands with an elevation of more than 2000 meters and land degradation in the form of narrow and parallel valleys, and very small plains separated by heights. In this region, the climate is cold and humid due to high altitudes and moisture absorption that flows to the Atlantic Ocean and the Mediterranean Sea to the east. In addition, the lack of development of communication paths and the extreme environmental conditions are factors in the absence of large urban centers and migration out of this basin, particularly the plains of Isfahan [20]. Surface rivers and their inlets are the main environmental phenomenon of these valleys that originate from Bakhtiari and Khansar mountains. Most of the current population centers are located near these water resources and on the upstream terraces of these rivers. The mountain valleys of Daran are larger than Fereydoun-Shahr and Boeing and have provided the possibility of aquatic farming. The natural feature of the region is that from the west and northwest to the east, a tangible change from mountains to plains can be observed where in fact the area is covered with alluvial heights. One of the best of these plains is the Zayandeh-Rud River plain. This area, which originates from grassland alluvials and ends with a slope to the Gavkhoni lagoon in the southeast of Isfahan, lies between the two western mountain ranges. The most important elevations of the Dalan-kuh, Bizeh and Damandar areas and the highest peaks of the Khan-kuh are 4040 meters above sea level [21]. The studied basin is a cold mountainous region with relatively high rainfall, particularly in Daran and Fereydoun-Shahr (250-450 mm of rainfall per year). This part of the basin has a cold climate with temperatures as low as -20 degrees Celsius in January and February, and cool summers with temperatures between 25 and 30 degrees Celsius suitable for the tribes of the region. The highest atmospheric precipitation is in the form of snow, its level in millimeters varying from year to year. The vegetation in the western half is pasture in the form of shrubs and shrubs of the Zagros type, similar to those found in Lorestan and Bakhtiari. Varieties of birds such as eagles, ducks, quails, pigeons and doves and animals such as wolves, jackals, hogs, rams, goose, mice, rabbits and wild cats. Due to the type of climate, the studied area was a perfect area for nomadic settlers. The forced settling of nomadic tribes at the threat of the bayonet began in 1929, and gradually all the nomads became permanent settlers of the area [22]. The present study mostly identified migratory settlements. Because of the proximity of Garmsir (Gheshlagh/ warmer areas) to Sardsir (Yelagh / cooler areas), created livelihoods were based on migratory economic coexistence. In fact, people chose this lifestyle to adapt to the environment. The tribes of this area would go to Khuzestan (south) during the cold season and returned to the region in the hot season.

4. Statistical Population of the Study

In the western and northwest areas of Isfahan Province, an area of approximately 22700 square kilometers (excluding Khomeini, Shahr, Falavarjan and Najaf-Abad), Iron Age III sites were identified extending from Boine and Miyandasht to the urban centre of Isfahan city. Of the 48 sites, 2 sites are located in Boeing and Miyandasht, 10

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sites in Fereydoun-Shahr, 19 sites in Daran, 14 in Chadegan, 3 in Tiran and Krvan and 1 in Isfahan city. In Najaf Abad, Khomeini Shahr and Falavarjan, which is located in the western and southern parts of the province, no areas have been identified thus far. Geographic maps were used to analyze these areas and the impact of environmental factors on how they are arranged. To do this, and for greater integration of the maps, Najaf Abad, Khomeini Shahr and Falavarjan were also included in the maps even though no Iron Age III enclosures were found.

5. History of Historical and Archaeological Research of the Study Area

The oldest evidence of the existence of ancient sites in the west of Isfahan Province is the Najm al-Molk (1983) travelogue which mentions visiting several ancient sites in the city of Chadgan. Maxim Siro(1978) also cited a cemetery with megalithic tombs in the area Subsequently, two specialist teams from the former Department of Anthropology and Popular Culture, were dispatched in 1958 (Yahya Kusari), to identify and record the ancient sites of Shahrekord, and in 1979 to study the areas that would be submerged by the Zayandeh-Rud River dam during water drainage.

The first team referred to several hills including the Kogang on the border between the two provinces of Chaharmahal-Bokhtari and Isfahan which although from their perspectives was not valuable, a number of pottery pieces relating to the Copper and Stone Ages and the beginning of the Elamite period were collected from the surface of the hill [23]. Subsequently, Salehi completed a brief review of the Zayandeh-Rud River / Pasazgan Basin in the Tal-Balagh villages in 2001 extending to the Zayandeh-Rud River connection. Between 2001 and 2005, a part of the Chadegan city of Dolatabad and Kogang in the west, Chadegan in the east, and the north coast of Zayandeh-Rud River were investigated. In this study, sites of the Copper and Stone Ages until the Islamic period were identified. In addition to artifacts belonging to Iron Age I and II, pottery dating back to Iron Age III were also found from a number of sites including the typical bright red to chickpea and pink colored bowls, Cebu and dishes with horizontal handles.

Other field works carried out in this area include the exploration of the "Gourtan ancient site"[24], "Review of prehistoric sites of Zayandeh-Rud River basin to Gavkhoni lagoon" as part of a PhD thesis[25], "Review of the city of Fereydoun-Shahr"[26], "Review of the Tiran and Karan townships"[27], "Review of the city of Daran"[28] and Distribution of copper-stone sites on the margin of the Plasagan River in the central part Daran County. Recently, a study was carried out with the aim of identifying Iron Age III sites through reviewing results of previous surveys as well as identification of newer sites in Daran, Fereydoun-Shahr, Boyin and Miyandasht, Tiran-Krone and Chadegan[29].

6. Method of Research

The present research aimed to analyze settlement patterns of the Iron Age III era in the study area using GIS (Geographic Information System (GIS)). The library-field method was used to collect the required data. The basic information was collected from books, documents and maps and completed with field studies. To prepare the maps of the region, based on the current review and the previous surveys, the sites were reviewed and recorded as points using the GPS device. The aim was to accurately analyze the ancient sites of this region in relation to the ecological characteristics of their settlements and their relative location along areas of natural resources. To achieve the desired goals, data on altitudes, slopes, landforms, land use, climate, rivers, communication paths and enclosures were input into the GIS maps software as layers. Each of the factors (layers) was compared to the sites and then evaluated. Then, each of these factors was analyzed in relation to the distribution and establishment of ancient sites. Finally, considering the output data, the distribution and the effect of geographic factors on the desired model extraction was studied. By preparing these information layers, analysis of environmental capabilities to adapt to the ancient sites and the settlement patterns of the area under study helped to determine their distribution status relative to the natural factors in the Iron Age III era. This research was based on a descriptive-analytic method with an emphasis on the role of natural factors in the distribution of Iron Age III settlements in the west and northwest of Isfahan Province.

6.1 Status of Deposits and Dispersion of Iron Age III Plots by Analyzing Environmental Variables

Environmental factors are usually considered in archaeological study models for a variety of reasons. Environmental data in the form of soils, geology, hydrology, and topographic maps are relatively easy to grasp. In addition, all classes and types of culture from simple collector-predator societies and primary farmers to advanced farmers and urban people respond to environmental conditions in their area of activity and settlement [30]. According to Toulon, habitation is an integral part of human life and its most important needs influence factors affecting the distribution of population and habitats in environmental variables including climate, vegetation, water resources, ripples (altitude and slope) and so on [31]. It is important to note that the area under study has attracted humans in different periods because of suitable geographical and environmental conditions and natural resources. Various factors were taken into consideration in the selection of an ancient site by human populations. Sometimes although one factor is more prominent, usually it is a part of a group of inter-related factors. Among the natural factors affecting the distribution of ancient settlements height, water resources, soil, slope percentage and direction, vegetation, and communication paths were investigated.

6.2 The Location of the Enclosures Relative to Sea Level

One of the important issues in the study of ancient sites is the recognition of different altitude levels. The results of these surveys can provide archaeologists with valuable information concerning the new ancient sites and the location of the sites in the past. Altitude in mountainous areas is one of the most important factors in the establishment of settlements because the height in addition to the influence of climatic elements such as temperature, precipitation and evaporation, affect the production of soil and appropriate or inappropriate conditions of residence [32]. Among the effects of climate on the altitude factor, one can study the number of freezing days and its impact on human biological activities [33].

Two distinct climatic conditions of mountains and plains exist in the study area. The west and northwest, closer to the center and parts of the south-east are covered by lowlands and more often with flat areas and plains. Thus, the city of Fereydoun-Shahr with a height of 2560 meters above sea level is the highest in Isfahan Province, but in its areas close to the entrance to Tiran and Karvan, elevation is reduced to altitudes of 1860 meters above sea level. This shows a change from mountains to plains. The largest part of the area is located in the plains due to its relatively moderate climatic conditions. The study of the distribution of the sites in relation to the topographical factor were mapped and based on elevation levels dispersion of the Iron Age III settlements which are indicated in Figure 2.

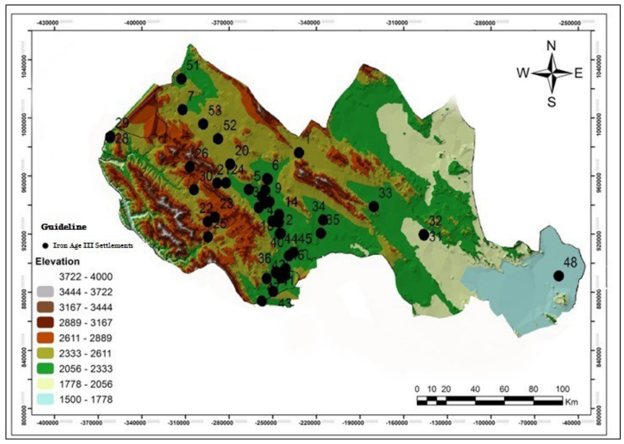

Figure 2. Dispersion of iron age III sites relative to altitude

Source: Field Survey (2017).

The zoning of the area in question is shown in Figure 2. Based on this feature, the area is divided into nine levels of elevation. The highest elevation is between 4000 and 3722 meters and the lowest elevation level is between 1,778-1,500 meters. The map (GIAS) shows that the majority of our study sites are at lower altitudes with 69.3% (33 sites) at an altitude of 2033-2333 meters, 18.9% (9 sites) at an altitude of 1800-2000 m, 10.5% (5 sites) at an altitude of 2600-2800 m, and 1.2% (1 site) at an altitude of 1700-1900 m; no remains of settlements were discovered at altitudes of 3167 up to 4000 meters. Most of the sites are located in the middle of the mountain plains. The average heights of most sites in the study area is in the range of 2333 to 2056 m. In fact, due to the presence of extreme slopes and high altitudes, the area provides a suitable area for human settlements along valleys and riversides. Furthermore, some sites are located at the intersection of mountains and plains. The study area is located in the highlands of Isfahan Province, particularly Daran and Fereydoun-Shahr city. Establishment of settlements at high altitudes was due to adequate rainfall and vegetation, particularly rangelands. At lower altitudes, habitation was established because of easier access to water resources and communication routes. The formation of settlements at high altitude were for the following reasons: 1- the need for security; 2-the availability of resources; 3-the existence of pastures; and 4- the existence of a fertile soil.

6.3 Location of the Sites Relative to the Slope of the Land

Slopes are one of the most important factors in the

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transformation of the roughness of the earth's surface [34], and thus directly or indirectly affects human life and activities. The most suitable slopes for the establishment and development of cities are between 0.5 and 10% [35]. Considering the importance of slope in agricultural, constructional and residential uses, the use of slope factor with other parameters can be an important contribution to measuring the power of the regions. Agriculture and particularly crop activities as the predominant employment in many rural settlements have a close relationship with slopes. In principle, it is possible to carry out agricultural activities, particularly crop growth at low altitudes. The analysis of the topographic factor and its role in the stability of settlements, regardless of slope, does not seem reasonable [36]. Low slope percentages result in better penetration of water to the ground and increased moisture storage, thus, it is very effective in keeping better heat storage in plants and livestock production. 56.7% of sites (27 sites) were situated at slopes of 0.08 degrees, 27.3% (13 sites) at slopes of 9-22, 14.1% (7 sites) at slopes of 23-40 and 2.1% (1 site) on flat ground without a slope (Figure 3).

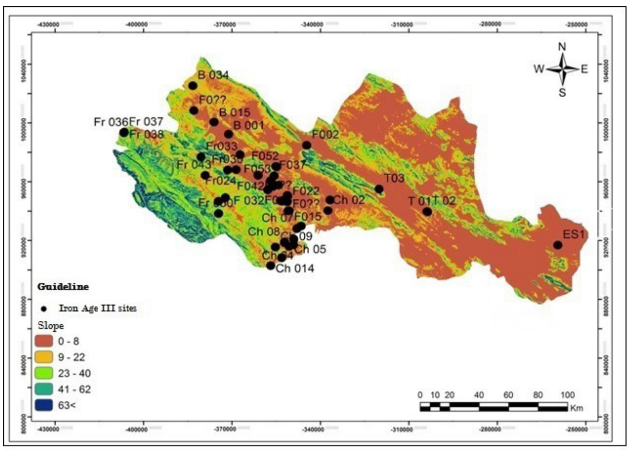

Figure 3. Dispersion of Iron Age III sites relative to the slope of the land

Source: Field Survey (2017)

6.4 Position of the Enclosures Relative to the Slope Direction

One of the most important influences on the ecological environment is the amount of sunlight received. 16.8% (8 enclosures) faced east, 7.35% (17 sites) faced southeast, 31.5% (15 sites) faced west, 8.4 (4 enclosures) faced north, 2.58% (1 site) was on a plain without facing any particular direction and 5.3% (3 sites) faced the south (Figure 4).

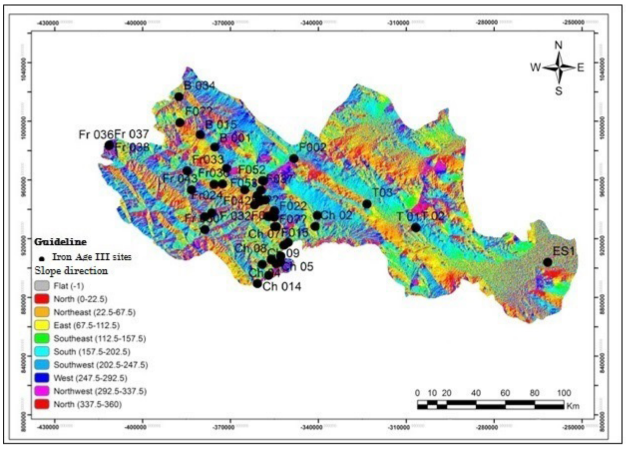

Figure 4. Dispersion of Iron Age III sites relative to the slope direction

Source: Field Survey (2017)

6.5 Location of Land Areas Relative to Land Use

In order to analyze the information obtained from land use, the soil texture, elevation and slope, geology, and the amount of water resources had to be considered. Another issue for consideration is the capacity of the land in the establishment of user types. The type of land as the settlement and location of human activities has the characteristics that determine how it is used. Land use and method of choosing development of appropriate activities are determined according to different regional conditions [37]. Land use is effective in dispersion and type of human activities, and it has the greatest impact on the distribution of settlement. Distance from water resources, vegetation cover, type of suitable soil cover, and even drainage of the land are influential environmental factors. In the study area, topography and land use did not play a significant role in establishment of settlements (Figure 5) indicating that the highest number of settlements were located on plains. Most of these settlements were formed along the Palasjan and Zayandeh-Rud Rivers, and infertile and fertile lands. Despite low altitudes, the density of large settlements in mountainous areas was low. 16.8% (8 sites), 12.6% (6 sites), 14.7% (7 sites), 7.56% (27 sites), and 4.2% (2 sites) of settlements were situated on arable lands, good pastures, croplands, dry and irrigated fields and forest lands, respectively.

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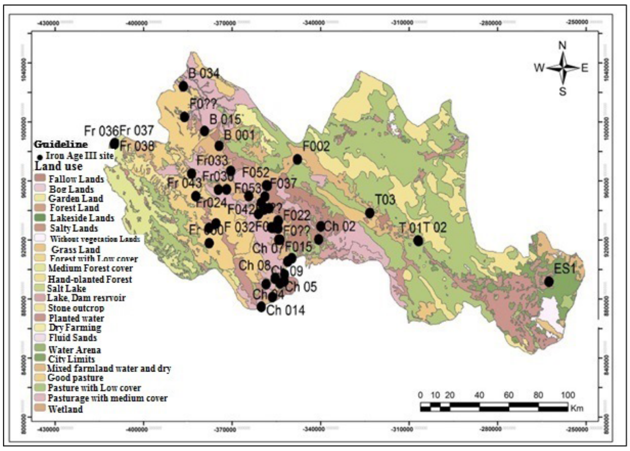

Figure 5. Dispersion of Iron Age III relative to land use

Source: Field Survey (2017)

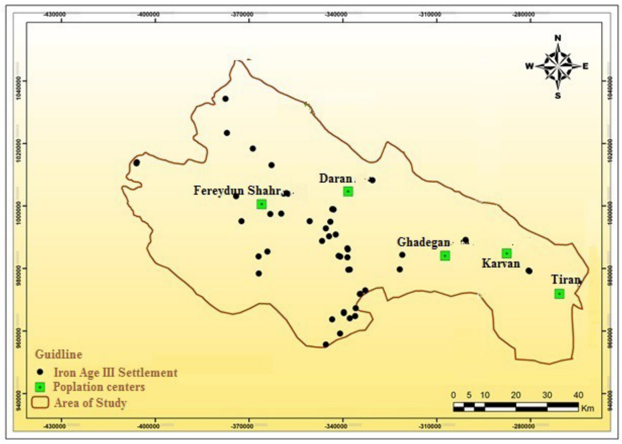

Figure 6. Dispersion of Iron Age III sites relative Population centers

Source: Field Survey (2017)

In the current research, land use was studied in relation to agriculture and rain water. This feature contributes to the proper position of grazing livestock and agriculture, which indicates the livelihoods of agriculture and livestock at high ranges. Due to the availability of adequate water resources at high altitudes and suitable rangelands and soils in the plains, the study area had favorable conditions for agriculture and horticulture. At high altitudes, due to the presence of pastures, it was a favorable region for the nomadic tribes and was suitable for livestock grazing. In mountainous areas, conditions were created for aquaculture along with rainfed farming. The location of the sites indicates climatic variation in terms of vegetation and was a favorable environment for crop (dry and irrigated) and livestock farming.

6.6 Situation of Sites in Relation to Today's Settlements

Creating a modern settlement on ancient sites suggests the continuity of settlements in remote areas in a geographic environment. According to the surveys, only 3 enclosures are located adjacent to today's population centers, and the rest of the sites are not related to large populated areas (Figure 6). However, during the survey it became clear that almost all of the sites are near the present-day villages, and this reflects the similarity of the current settlement pattern to that of the past suggesting continuity. This can be a sign of the existence of the proper and identical conditions of life from the past to the present. If we look at the present-day maps of the studied area, it is clear that all of today's settlements were created alongside communication paths as a linear settlement pattern.

6.7 Location of the Sites and Distance to the River

In Iran, mountains account for many of Iran's spatial features such as rainfall, vegetation, water and ice equilibrium, and most importantly the central civilization of Central Iran. In Zagros forests, the presence of water is much higher in the eastern part of the mountains and only approximately half of the annual precipitation is received compared to the western slopes [38]. The natural source of water in the studied area includes permanent and seasonal rivers as well as springs. The most important feature of water resources in this region is the seasonal surplus of water limited only to winter months. This abundance of water resources led to the emergence of rich habitats and attracted people to the study area in the first millennium BC. These kind of water resources makes this area a prerequisite for the settlement of demographic groups.

Due to the existence of water resources, the highest population densities were located in Daran, Fereydoun-Shahr, and Chadegan so that almost all of the sites are located on the alluvial terraces of the Zayandeh-Rud River and Palasjan Rivers. Considering the existence of Zayandeh-Rud River and its branches, this river is the main focus of populations and economy in the region. Other seasonal rivers also provide conditions for a group of temporary and seasonal habitats for migrants. Generally, seasonal settlements created in Iron Age III in these mountainous regions were planned for the same amount of water resources. In Chadegan and Tiran, due to decreasing slope, the amount of submerged river sediments caused valleys and surrounding lands to be more fertile and cultivated. The dispersal of ancient sites and settlements, particularly in Chadegan, follow the course of Zayandeh-Rud River and its related branches. Changes

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in the Zayandeh-Rud River and the fluctuation of glacial heights around Isfahan are also factors influencing the formation of human settlements in the west and northwest of Isfahan. The strip of inter-connected nodes or the remains of glacial lakes in villages and townships is still visible [39]. Figure 7 illustrates that more than 95% of the settlements were within 500 meters of the water source.

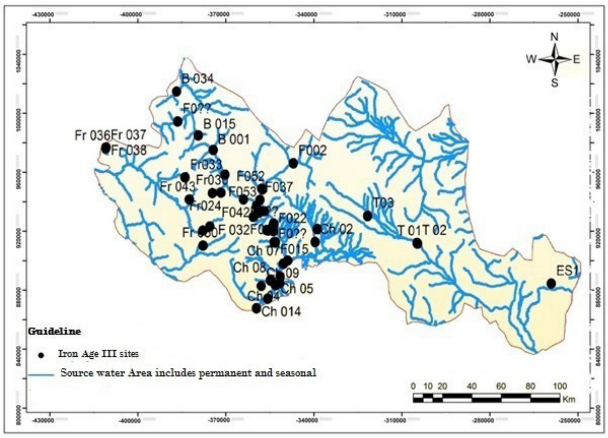

Figure 7. Dispersion of Iron Age III sites relative distance to the river

Source: Field Survey (2017)

6.8 Location of Sites in Relation to the Region's Climate

The magnitude of the impact of geographical and climatic factors (such as altitude, vegetation, etc.) is indicative of the weather in the area, thus providing a clear and comprehensive picture of the weather in each region [40]. The importance of climate in the formation of human settlements is such that changes in climatic elements can disturb the ecological balance of habitats. The most important climatic elements that have great influence are temperature and precipitation [41]. Despite the importance of elevation in the settlements, weather and its prominent role in determining the structure of the settlement pattern has a greater influence. An ancillary study of two caves and ancient fortresses dating back to the Middle Ages, approximately 60,000 to 40,000 thousand years ago provided new information regarding the vegetation and animal life of the Zayandeh-Rud River basin. The study of charcoal samples shows that in this period there were some tree-covered beams along the shrublands including those of willows and poplar trees. There were also pistachio forests in the area during this period. The inhabitants of the Ghaleh Bozi used these trees as fuel for their stoves [42].

Moreover, a survey to identify the amount of carbonate in the soil and the effect of greenhouse gases during the Quaternary glacial period on soil type in the eastern part of the city of Isfahan, between Zayandeh-Rud River Dam in Chadegan and Gavkhoni Lagoon, was carried out in 2004. The extent and type of vegetation and climate in the region was also discovered. In this study, plants from the spongy family were identified and its spread over the last glacial period in the catchment area of Zaryar and Mirabad lakes were identified to be as a result of the dominance of the cold and dry climatic conditions in western Iran [43].The results show that the current climate in the region is not significantly different from the past. 7.35% (17 sites), 37.8% (18 sites), 8.26% (8 sites), 6.8% (3 sites), and 8.4% (4 sites) of sites, were semi-arid, semi-humid, humid, medium semi-dry and dry areas, respectively illustrating the pattern of migration to semi-humid areas. Of course, the issue of precipitation has also been very important in this regard because rainfall is crucial to both agriculture and livestock farming. The amount of rainfall and access to the river are also very important. The greatest transaction and proximity of the sites are in medium to high rainfall areas, which might be justified by groups based on selective livelihoods.

6.9 The Location of the Enclosures Relative to the Distance from the Roads and Communication Paths

Low degree of slope in the areas provided better access to communication paths. Mobility with the help of the road network aided transportation and movement of populations and expansion of trade. Most of the sites are located along today's communication paths. It is noteworthy that communication paths are needed in every region's economic development. Livestock activities and even livestock need roads and require communication paths to exchange products. The area has several passageways which have been used by nomadic tribes since ancient times. The studied area has the most commonly used passageways which

were used by nomadic tribes in the distant past. For these reasons, there is still a road connection. Due to the existence of mountainous areas, communication paths were required for establishing regional and trans-regional relations with the lowlands. As far as the distance and proximity of the sites are concerned, four levels were considered: the first floor was 0-500 meters, the second floor was 1500-500 meters, the third floor was 2500-1500 meters, and the fourth floor was 3500 -2500 meters. In terms of correlation with communication routes, 37.8 percent (18 sites) of sites were at 500 meters, 25.2 percent (12 sites) were at 1500 meters, 23.1 percent (11 sites) were at 2500 meters and 12.6 percent (6 sites) were at 3500 meters (Figure 8).

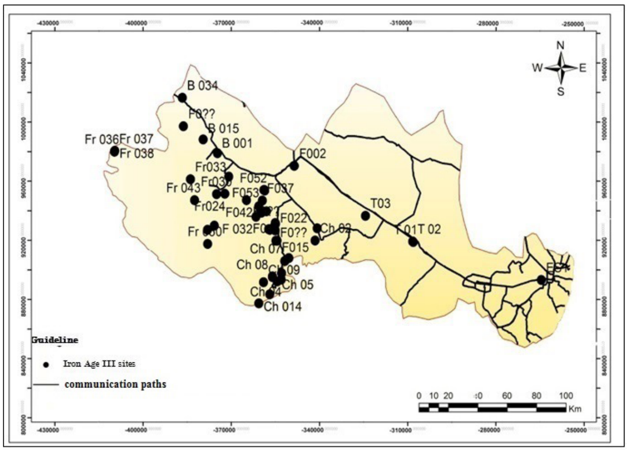

Figure 8. Dispersion of Iron Age III sites relative to the distance from the roads and communication paths

Source: Field Survey (2017)

6.10 Location of the Sites in Relation to the Geological Structure and Faults of the Region

Looking at human settlements, it can be observed that most of these sites, and even today's villages, tended to reside in the middle of the plains and almost all maintained their distance to the mountains. This indicates that cold weather is an important factor in human habitations beings near plains and away from heights. Some of the sites such as Asgaran in Tiran and Krone settled between the mountains and the plains.

Environmental changes in the Quaternary period are important in terms of renewable natural resources, land use, erosion sensitivity, underground and surface water storage, dependent vegetation, the determination of archaeological age, and many other important issues. In geological studies and in terms of stratigraphic divisions, Quaternary period is considered the third geological age (Cenozoic) and is approximately equal in length to the approximate length of the Holocene and Pleistocene eras. During this period, due to the presence of atmospheric rainfall, large floods were created and floods in turn carried the material from the heights to the downstream areas (Figure 9).

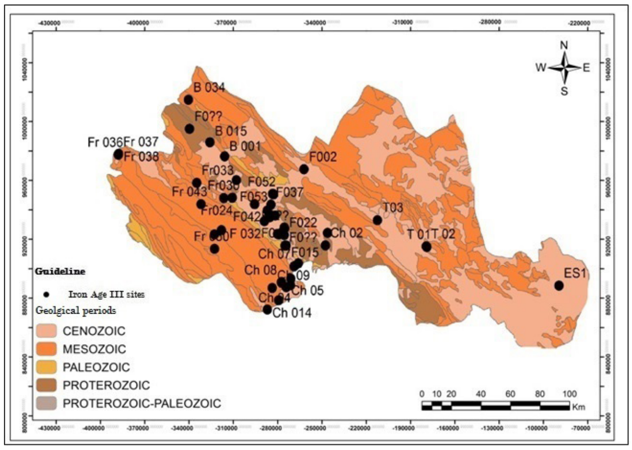

Figure 9. Dispersion of Iron Age III sites relative to the faults of the region

Source: Field Survey (2017)

In this way, alluvial deposits have been the most common among quaternary deposits. Alluvial soils are suitable for agricultural activities. In the atmospheric rainfall in the Ice Age during the Quaternary period, the lignite line hosted by the (impenetrable) rocks created numerous lagoons. Figure10 shows that the sites under study covered the second and third periods of geology. 69.3% of the sites were Quaternary(33 sites), 10.5% were Cretaceous (1 site), 8.4% were Peruvian Toucu before Cretaceous (4 sites), 10.5% (5 sites) were of the Jurassic Age (Figure 10). Establishments along the faults was because of easier access to groundwater resources.

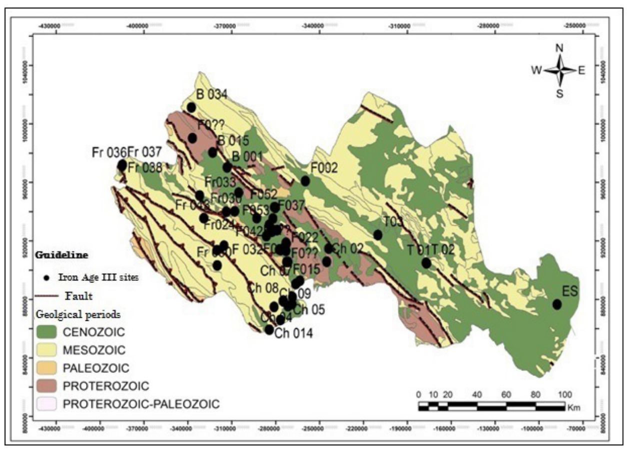

Figure 10. Dispersion of Iron Age III sites relative to the geological structure

Source: Field Survey (2017).

7. Discussion and Conclusion

Natural environment has a great influence on the distribution and location of ancient sites, and is one of the

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factors contributing to the appearance of the sites. Using GIS software helped us to increase the speed and strength of analysis and conclusions. In this research, the effect of natural factors such as height, water resources, climate, land use, percentage and direction of slope, distance and proximity to communication paths and geological structure of the study area were compared to the distribution of the Iron Age III settlements in the west and north of Isfahan Province.

Investigating the distribution patterns of the ancient sites of Iron Age III in this geographical area shows that human populations were able to overcome the natural environment. There are two different views in this area: one of the heights and the other open valleys leading to the plains, so the chosen settlement pattern is in line with the same environmental characteristics of the area. The open valleys leading to the fertile plains along with the alluvial deposits of the Zayandeh-Rud River and its sub-branches in the plains have the most settlements.

Given the environmental conditions prevailing in the area, most of the identified sites are of temporary settlements (extramural). The characteristics of these sites are small, and the number of low cultural materials is superficial and not thicker than their ancient deposits. Today, in the villages of Chadegan, nomadic tents are still seen. The mentioned environmental factors influenced the formation of Iron Age III settlements in the target area. Evidence suggests that the west and northwest of Isfahan played a significant role in Iron Age III. As a result of the archeological study of west and northwest of Isfahan Province, 53 Iron Age III areas were identified. According to the maps prepared by GIS, the factors of height, proximity to water resources, distances and proximity to communication paths are the most important factors in distribution and location of the settlements. Therefore, the establishment of settlements in the study area was influenced by the environmental conditions of the region, confirming the existence of Zayandeh-Rud River watershed and its branches led to the creation of permanent water resources in the region which in turn created suitable conditions for habitation and fertile soils necessary for agriculture. The existence of medium to high rangelands at high altitudes formed suitable conditions for livestock farming an important factor in nomadic lifestyles.

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